MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY

Vol. 99 No. 4

1939 FEBRUARY 10

ANNUAL GENERAL MEETING

Dr. H. Spencer Jones, President, in the Chair.

The Minutes of the preceding Annual General Meeting, and the Minutes of the Special General Meeting held 1938 April 8 were read and confirmed.

The President announced that M. Bernard Lyot had been appointed George Darwin Lecturer for 1939, and that M. Lyot would deliver the Lecture (which would be illustrated by a film) at the Ordinary Meeting of the Society on May 12.

The election by the Council of the following Fellows was duly confirmed :—

William Charles Aubrey-Rees, 63 Cannon Lane, Pinner, Middlesex ;
Edward Barker-Jones, B.Sc., 4 St. George's Avenue, Grays, Essex ;
Samuel Morris Green, 22 Church Street, Prescot, Lancs ;
B. Gopala Narayan, B.Sc., Solar Physics Observatory, Kodaikanal, S. India ;
Robert Albert Newing, University College of North Wales, Bangor ;
Albert Thomas Price, M.Sc., Imperial College of Science and Technology, South Kensington, London, S.W. 7 ; and
John Wadsworth, late Director of the Apia Observatory, 16 Wavertree Court, Streatham Hill, London, S.W. 2.

The following candidates were proposed for election as Fellows of the Society, the name of the proposers from personal knowledge being appended :—

Akbar Ali, M.A., 15 Chatsworth Avenue, London, N.W. 4 (proposed by C. C. L. Gregory) ;

UNIVERSITY LIBRARY LEEDS

Ibrahim Hilmy Abd-el-Rahman, B.Sc., Ornan Court, London, N.W. 3 (proposed by C. C. L. Gregory);

Pares-Chandra Chaudhuri, M.Sc., 54 Oakley Square, London, N.W. 1 (proposed by C. C. L. Gregory);

William Henry de Bargue Hubert, 44 Wimpole Street, London, W. 1 (proposed by J. A. Carroll);

William Jacob Jones, D.Sc., F.I.C., F.Inst.P., Professor of Chemistry, University College, Cardiff (proposed by C. J. M. Aanensen);

Miss Eleanor Margaret Peachey, 115 Greenhill, Hampstead, London, N.W. 3 (proposed by C. C. L. Gregory); and

L. M. Verghese, B.Sc., Ornan Court, London, N.W. 3 (proposed by C. C. L. Gregory).

The President delivered an Address on "Some Problems of Meridian Astronomy" (see p. 424).

Visitors were then requested to withdraw and the Society proceeded to the formal business of the Meeting.

The Report of the Auditors was read (see p. 289), and the list of Fellows in arrear was laid on the table.

The Treasurer gave some explanation of details of the accounts.

A vote of thanks to the Auditors of the Treasurer's Accounts for 1938 was proposed and carried unanimously.

The Annual Report of the Council was partly read.

The Secretaries moved the following resolution on behalf of the Council:—

"*Resolved:* That the Society's duplicate copy of the Artaud portrait of Sir William Herschel be presented to the Royal Observatory, Greenwich."

Professor Greaves explained that on the occasion of the Herschel bi-centenary on November 15 last, Sir John Herschel presented to the Society the copy of the portrait of Sir William Herschel which was painted by Artaud for Caroline Herschel, and this now hangs above the President's chair. The copy previously in the Society's possession was commissioned by the Council in 1913, and was copied by F. Leist, of Chelsea, from the original by Artaud in Sir John Herschel's possession. In 1933 Miss Hardcastle very kindly had this copy varnished and re-conditioned. It is now proposed to present this copy to the Royal Observatory, Greenwich.

The resolution was carried unanimously.

It was proposed and carried that the Report of the Council be received and adopted, and that it be printed and circulated in the usual manner, together with the Report of the Auditors and the President's Address.

The President having appointed the Scrutineers, the Society proceeded to the ballot for Officers and Council for the ensuing year. The names of those elected are given on p. 435.

Dr. Steavenson showed some of the slides recently added to the Society's collection.

The thanks of the Society were given to the retiring President (Dr. Spencer Jones), Secretary (Professor Greaves) and other retiring members of Council.

The thanks of the Society were also given to the Scrutineers of the ballot.

The Meeting then adjourned.

REPORT OF THE COUNCIL TO THE HUNDRED AND NINETEENTH ANNUAL GENERAL MEETING OF THE SOCIETY.

PROGRESS AND PRESENT STATE OF THE SOCIETY

	Patron	Institutional Members	Honorary Member	Fellows		Associates	Total
				Compounders	Annual Subscribers		
1937 December 31	1	4	1	201	662	48	917
Since elected	...	...	...	+ 3	+34	+ 3	...
Deceased, 1938	...	...	...	− 9	− 8	− 4	...
Resigned	...	...	...	...	−13	...	...
Since compounded	...	...	...	+ 1	− 1	...	...
Removed from list	...	...	...	...	−13	...	...
1938 December 31	1	4	1	196	661	47	910

(Six Associates are also Fellows, and are therefore counted twice in the above table.)

RECEIVED

	£ s. d.	£ s. d.
Balances, 1938 January 1:—		
In hand of Assistant Secretary on Petty Cash Account	0 11 5	
At Bankers', on Current Account	804 5 8	
At Bankers', on Deposit:—		
Cash Balance of Spencer Bequest £148 10 2		
Advance payments for Franklin-Adams Charts, Section 3 99 0 0		
	247 10 2	
At Bankers', on "C" Account:—		
Trust Funds £175 19 0		
Proceeds of Sale of Duplicate Books 41 13 0		
	217 12 0	
		1269 19 3
Received on account of Dividends:—		
£1250 Metropolitan Consolidated 3% Stock	37 10 0	
£2000 Swansea Corporation 3½% Stock	70 0 0	
£2287, 6s. 9d. East Indian Railway 3% Debenture Stock	50 3 5	
£5125 London, Midland and Scottish Railway 4% Debenture Stock	151 3 9	
£750 London, Midland and Scottish Railway 4% Preference Stock	22 2 6	
£2400 Gas Light and Coke Co. 3% Consolidated Debenture Stock	53 2 0	
£2000 Commercial Gas Co. 3% Debenture Stock	43 10 0	
£1035 Agricultural Mortgage Corporation 4% Debenture Stock, 1961–91	33 15 6	
£695, 16s. Conversion Loan 3½% Stock, 1961	24 7 0	
£419, 17s. 11d. Conversion Loan 4½% Stock, 1940–44	18 17 10	
£700 Birmingham Corporation 3% Inscribed Stock, 1947	21 0 0	
£496 Consolidated Loan 4%	19 16 8	
£2000 New Zealand Consolidated 3½% Loan, 1940	70 0 0	
£1000 Hull Corporation 4½% Redeemable Stock, 1952–72	45 0 0	
£800 War Loan 3½% Inscribed Stock	28 0 0	
£500 New South Wales 4% Stock, 1942–62	14 15 0	
£1000 Central Electricity Board 4½% Stock, 1947–82	33 3 9	
£1156, 1s. 5d. Metropolitan Water Board 3% "B" Stock	25 11 6	
Income Tax refunded, 1937 April–1938 April	141 2 10	
Interest on Deposit Account	2 14 9	
	905 16 6	
Sales of Publications £347 14 0		
Reprints 51 3 9		
	398 17 9	
Sales of Photographs	52 15 6	
Miscellaneous Receipts:—		
London Mathematical Society, Expenses of Meetings £31 10 0		
Estate of the late Archdeacon Potter 10 13 6		
Sale of Old Telescope, etc. 26 2 0		
Assistant Secretary and Clerk, Pension Premiums 19 5 0		
Donation from University of Michigan 12 0 0		
Use of Telephone 0 11 7		
Excess on Subscriptions 0 4 5		
Postages, etc., repaid 3 12 6		
	103 19 0	
		1461 8 9
Porter, Pension Contributions, 1938 Aug. 1–Dec. 31, at 5s. a week		5 10 0
Franklin-Adams Charts		288 0 0
Proceeds of Sale of £200 War Loan 3½% Inscribed Stock (Spencer Bequest)	198 11 6	
Dividends on £700 War Loan 3½% Inscribed Stock (Spencer Bequest) *	24 10 0	
		223 1 6
Received on account of Subscriptions:—		
560½ Annual Contributions for 1938 (including 3 Institutional Membership Fees)	1177 1 0	
28 Annual Contributions for 1939 in advance	58 16 0	
2 Annual Contributions for 1940–41 in advance	4 4 0	
35 Admission Fees	73 10 0	
32 First Contributions at 2 guineas	67 4 0	
1 First Contribution at 1 guinea	1 1 0	
Arrears paid off:—		
5 for 1936 (less 16s.) £9 14 0		
30½ for 1937 (less 5s.) 63 16 0		
	73 10 0	
		1455 6 0
Composition Fees		126 0 0
Trust Funds:—		
Dividends:—		
£1212, 13s. 3d. East Indian Railway 3% Debenture Stock	26 12 2	
£542, 18s. 2d. India 3½% Stock	19 0 0	
£965 Agricultural Mortgage Corporation 4½% Debenture Stock, 1961–91	31 9 8	
£1004 Consolidated Loan 4%	40 3 2	
£540, 10s. 4d. War Loan 3½% Inscribed Stock (Stillhamer and Goodridge Bequests)	18 18 4	
Donation from General Fund (balance of George Darwin Lecture Fee)	9 16 10	
Income Tax refunded, 1937 April–1938 April	19 18 8	
		165 18 10
		£4995 4 4

* Added to value of Bequest in Balance Sheet.

Examined and found correct.

(Signed) W. E. CANDLER.
F. J. SELLERS.

1939 *January* 19.

ASTRONOMICAL SOCIETY, FROM 1938 JANUARY 1 TO DECEMBER 31

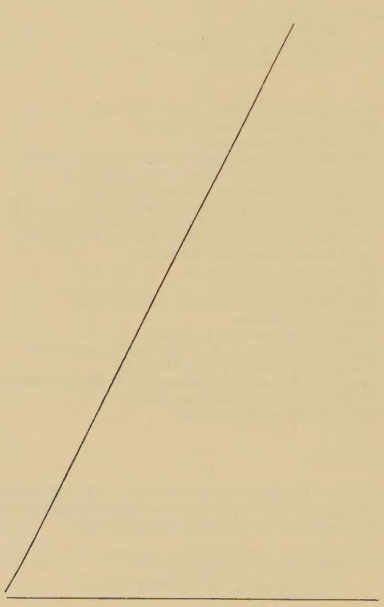
Account

PAID

	£ s. d.	£ s. d.
Assistant Secretary: Salary	270 0 0	
Clerk: Salary	190 0 0	
Assistant Secretary and Clerk, for work done for London Mathematical Society	10 0 0	
Pension Premiums for Assistant Secretary and Clerk	57 15 0	
Porter and Wife: Wages	161 19 0	
Health and Unemployment Insurance	8 7 11	
		698 1 11
Fire and Accident Insurance	18 1 7	
Telephone	15 8 1	
Telegraphic Address	2 0 0	
Water Rate	12 6 8	
		47 16 4
Postage and Packing:—		
Monthly Notices, etc.	153 7 1	
Office Postages	58 6 7	
		211 13 8
Printing, etc.:—		
Monthly Notices (Vol. **98**, Nos. 1–9)	950 12 8	
Geophysical Supplements (Vol. **4**, Nos. 4, 5)	116 14 1	
Occasional Notes, Nos. 1, 2	35 18 6	
Memoirs (Vol. **65**, Part 4, Vol. **66**, Part 1)	78 19 11	
Reprints	119 8 7	
Charter and Bye-laws	23 0 3	
Miscellaneous	64 10 6	
Photo-engraving:—		
Monthly Notices £53 2 0		
Geophysical Supplements 9 13 10		
Occasional Notes 11 16 5		
	74 12 3	
		1463 16 9
Reproduction of Photographs for sale	71 6 11	
Stationery and Office Expenses	48 6 4	
Hire of Cinematograph	4 8 0	
Purchase of 1st edition Franklin-Adams Charts	5 5 0	
Expenditure from Potter Fund (Library)	9 2 0	
Library Expenditure (General Fund)	52 13 11	
Subscriptions to National Central Library (1938–39)	2 2 0	
Subscription to International Telegrams Bureau	1 12 5	
Expenses of Herschel Bi-centenary Celebration	70 18 8	
Authorised Travelling Expenses	27 2 0	
Heating and Lighting	120 2 11	
Fittings and Repairs	28 16 10	
Balance of George Darwin Lecture Fee	9 16 10	
Engraving Medals	0 19 6	
House Expenses and Laundry	42 6 3	
Expenses of R.A.S. Meetings and Committees	19 10 4	
Expenses of Geophysical Meetings	6 10 8	
Expenses of London Mathematical Society Meetings	6 13 1	
Bank Charges and Cheque Books	2 12 1	
Miscellaneous Expenditure	12 0 7	
		542 6 4
		2963 15 0
Porter's Pension, First Premium 1938 Aug. 1–1939 July 31	... ...	26 6 0
Purchase of £500 3% National Defence Loan, 1954–58	... ...	490 0 0
Expenditure on Franklin-Adams Charts	... ...	250 14 9
Expenditure from Spencer Bequest:—		
Purchase of Instruments	124 7 0	
Shelving, etc., for Spencer Room	193 5 0	
		317 12 0
Stair Carpet and Matting	... ...	53 6 7
Expenditure on Trust Accounts:—		
George Darwin Lecture Fee	50 0 0	
Turnor and Horrocks Fund (Library)	17 4 2	
Harry Watson Fund (Library)	53 14 8	
Lee and Janson Fund	22 2 0	
Jackson-Gwilt Fund	50 0 0	
		193 0 10
Balances, 1938 December 31:—		
In hand of Assistant Secretary on Petty Cash Account	5 4 10	
At Bankers', on Current Account	450 14 8	
At Bankers', on Deposit (Cash Balance of Spencer Bequest)	53 19 8	
At Bankers', on "C" Account:—		
Trust Funds £148 17 0		
Proceeds of Sale of Duplicate Books 41 13 0		
	190 10 0	
		700 9 2
		£4995 4 4

Revenue

	£	s.	d.	£	s.	d.
To General Expenditure as per Cash Account	2963	15	0			
,, Porter's Pension Premium from August 1 to December 31 at 10s. a week, +6s.	11	6	0			
,, Reserve for Accounts due but not presented...	140	0	0			
	3115	1	0			
Less Reserve for Accounts due 1937, now written back ...	285	0	0			
				2830	1	0
,, Amount transferred to Composition Fees Reserve Fund in 1938				126	0	0
,, Special Repairs and Maintenance Account: Annual Reserve, 1938 ...				60	0	0
,, 19 Annual Contributions in Arrears (1936–37) written off ...	39	18	0			
,, 1 Part Contribution in Arrear (1935) written off	1	11	0			
,, 13 Annual Contributions 1938 written off as per contra ...	27	6	0			
				68	15	0
,, Excess of Income over Expenditure, 1938				94	17	11



£3179 13 11

Examined and found correct.

(Signed) W. E. CANDLER.
F. J. SELLERS.

1939 *February* 2.

Account, 1938

			£	s.	d.	£	s.	d.
By	560½	Annual Contributions 1938, including 3 Institutional Membership Fees	1177	1	0			
,,	23	ditto, paid 1937 and now matured	48	6	0			
,,	63½	ditto, outstanding (including 1 Institutional Membership Fee)	133	7	0			
,,	13	Contributions for 1938 due, but unpaid, in respect of Fellows resigned, or names removed, and written off per contra	27	6	0			
						1386	0	0
,,	32	First Contributions at 2 guineas...	67	4	0			
,,	1	ditto at 1 guinea	1	1	0			
,,	1	ditto outstanding	1	1	0			
	34					69	6	0
,,	35	Admission Fees at 2 guineas	73	10	0			
,,	1	ditto outstanding	2	2	0			
	36					75	12	0
,,	3	Composition Fees (Initial)	94	10	0			
,,	1	Since compounded at £31, 10*s*.	31	10	0			
	4					126	0	0
,,		6% of Composition Fees Reserve Fund as per Balance Sheet, transferred to Current Revenue				44	8	0
,,		Sundry Debtors, 1938				17	11	2
,,		Dividends, Sales of Publications, Photographs, and Miscellaneous Receipts, as per Cash Account ...	1461	8	9			
,,		Porter's Pension Contributions, 1938 August–December ...	5	10	0			
			1466	18	9			
Less		Payments due 1937 (£17, 4*s*. 10*d*. *less* £1, 10*s*. 10*d*. still outstanding) ... £15 14 0						
		Advance payments for Publications, 1939 53 4 10						
		Income Tax (General Fund) 1937 April–December, refunded in 1938 ... 86 0 4						
			154	19	2			
						1311	19	7
,,		Payments for *Monthly Notices*, Vol. 98, received in 1937 and now matured				49	9	9
,,		Income Tax (General Fund) deducted at source 1938 April–December, not yet refunded				99	7	5
						£3179	13	11

Balance Sheet

LIABILITIES

	£ s. d.	£ s. d.
28 Subscriptions for 1939, paid in 1938		58 16 0
2 Subscriptions for 1940–41, paid in 1938		4 4 0
Sundry Creditors for Accounts due but not presented ...	140 0 0	
Amount owing, Repairs and Maintenance Account	131 2 4	
		271 2 4
Cash Balances of Trust Funds—		
Turner and Horrocks Fund	8 1 3	
Harry Watson Fund	38 2 0	
Jackson-Gwilt Fund	9 5 6	
Lee and Janson Fund	54 8 4	
George Darwin Lectureship Fund	20 1 7	
A. G. Stillhamer Trust	17 4 0	
Goodridge Bequest	1 14 4	
		148 17 0
Trust Funds (Capital), as per contra		3,514 15 0
Income Tax on Trust Funds, 1938 April–December, not yet refunded		19 8 11
Special Fund (Capital), as per contra		1,460 0 0
Composition Fees Reserve Fund—		
As at 1937 December 31	614 0 9	
Received in 1938	126 0 0	
	740 0 9	
Less transferred to Current Revenue	44 8 0	
		695 12 9
Franklin-Adams Charts—		
Balance of liability from 1937	101 3 10	
Received in 1938 ... ... £288 0 0		
Less due in 1937 ... ... 45 0 0		
	243 0 0	
Due for one set	27 0 0	
	371 3 10	
Less expenditure on charts, 1938	250 14 9	
		120 9 1
Advance receipts for publications, 1939		53 4 10
General Fund—		
As at 1937 December 31	19,639 17 9	
Add Credit for overpayment on publications, 1932, now expired	0 11 0	
	19,640 8 9	
Add Dividends, Spencer Bequest	24 10 0	
	19,664 18 9	
Deduct Loss on sale of War Stock (Spencer Bequest) ...	2 7 0	
	19,662 11 9	
Deduct Cash Expenditure from Spencer Bequest, 1938 ...	317 12 0	
	19,344 19 9	
Add Excess of Income over Expenditure, 1938	94 17 11	
		19,439 17 8
		£25,786 7 7

Examined and found correct.

(Signed) W. E. CANDLER.
F. J. SELLERS.

1939 *February* 2.

1938 *December* 31

ASSETS

	£ s. d.	£ s. d.
Sundry Debtors for Subscriptions in Arrears—		
1 for 1936	2 2 0	
17½ for 1937 (+5*s*.)	37 0 0	
63½ for 1938	133 7 0	
1 First Contribution for 1938, outstanding	1 1 0	
1 Admission Fee for 1938, outstanding	2 2 0	
		175 12 0
Sundry Debtors, 1937		1 10 10
Sundry Debtors, 1938		17 11 2
Due for Franklin-Adams Charts		27 0 0
Investments of General Fund, valued as in 1937 Balance Sheet	18,649 10 11	
Add Purchase of £500 National Defence Loan, valued at cost...	490 0 0	
		19,139 10 11
Investment of Spencer Bequest—		
As at 1937 December 31	732 11 9	
Less sale of War Stock 3½%... ... ... £198 11 6		
Loss on sale 2 7 0		
	200 18 6	
		531 13 3
Investments of Special Fund, valued at cost		1,460 0 0
Investments of Trust Funds, valued as in 1937 Balance Sheet		3,514 15 0
Income Tax 1938 April–December, deducted at source, not yet refunded—		
General Fund...	99 7 5	
Trust Funds	19 8 11	
		118 16 4
Pension Premium for Porter, paid in advance for 1939 to July 31		15 0 0
Sundry Balances—		
In hand of Assistant Secretary on Petty Cash Account ...	5 4 10	
At Bankers', on Current Account	450 14 8	
At Bankers', on Deposit (Cash Balance of Spencer Bequest)	53 19 8	
At Bankers', on " C " Account—		
Trust Funds £148 17 0		
Sales of Books Fund 41 13 0		
	190 10 0	
		700 9 2
Repairs Suspense Account—		
Expenditure 1938:		
Stair carpets and matting	53 6 7	
Redecorations	131 2 4	
	184 8 11	
Less Reserve 1937 ... ... £40 0 0		
Reserve 1938 ... ... 60 0 0		
	100 0 0	
		84 8 11
		£25,786 7 7

INVESTMENTS

As at 1938 December 31

General Fund

£1250 Metropolitan Consolidated 3 per cent. Stock, 1941.
£2000 Swansea Corporation 3½ per cent. Stock.
£2287, 6*s.* 9*d.* East Indian Railway 3 per cent. New Debenture Stock.*
£5125 London, Midland and Scottish Railway 4 per cent. Debenture Stock.*
£750 London, Midland and Scottish Railway 4 per cent. Preference Stock.*
£2400 Gas Light and Coke Co. 3 per cent. Consolidated Debenture Stock.*
£2000 Commercial Gas Co. 3 per cent. Debenture Stock.*
£496 Consolidated 4 per cent. Loan, 1967.
£500 Agricultural Mortgage Corporation, Ltd., 4½ per cent. Debenture Stock, 1961–91.*
£1000 Hull Corporation 4½ per cent. Redeemable Stock, 1952–72.
£1000 Central Electricity Board 4½ per cent. Stock, 1957–82.*
£2000 New Zealand 3½ per cent. Loan, 1940.
£700 Birmingham Corporation 3 per cent. Inscribed Stock, 1947.
£1300 War Loan 3½ per cent. Inscribed Stock.
£500 New South Wales 4 per cent. Stock, 1942–62.*
£1156, 1*s.* 5*d.* Metropolitan Water Board 3 per cent. "B" Stock.*
£500 National Defence Loan, 1954–58, 3 per cent. Bonds.*

Grove-Hills Special Fund

£419, 17*s.* 11*d.* Conversion Loan 4½ per cent., 1940–44.
£695, 16*s.* 0*d.* Conversion Loan 3½ per cent., 1961.
£535 Agricultural Mortgage Corporation, Ltd., 4½ per cent. Debenture Stock, 1961–91.*

Trust Funds

£1212, 13*s.* 3*d.* East Indian Railway 3 per cent. New Debenture Stock.*
£542, 18*s.* 2*d.* India 3½ per cent. Stock.
£1004 Consolidated 4 per cent. Loan, 1967.
£965 Agricultural Mortgage Corporation, Ltd., 4½ per cent. Debenture Stock, 1961–91.*
£540, 10*s.* 4*d.* War Loan 3½ per cent. Inscribed Stock.

* Taxed at source.

REPORT OF THE AUDITORS FOR THE YEAR 1938

We have examined the Treasurer's account of receipts and expenditure, the Revenue Account and the Balance Sheet for the year 1938, and have certified them to be correct. All the investment holdings have been certified by the Bank of England or by the Westminster Bank.

The excess of £94, 17*s.* 11*d.* of income over expenditure is highly satisfactory in view of the facts that the sum of £60 has been set aside this year towards repairs and maintenance, that extraordinary expenditure of £70, 18*s.* 8*d.* was incurred for the Herschel Bicentenary Celebration, and that two numbers of a new publication, *Occasional Notes*, have been issued.

A contributory pension scheme for the benefit of the porter and his wife has been inaugurated.

The sum of £317, 12*s.* from the Spencer Bequest has been expended during 1938 on the purchase of two Ross wide-angle lenses and a plane diffraction grating by Hilger, which are on loan to Fellows, and the provision of shelving and cupboards for the Spencer Room, which has relieved some of the congestion in the Main Library.

The dividends from the investment of the A. G. Stillhamer Trust are being allowed to accumulate, by consent of the donor.

Composition fees amounting to £126 have been received and added to the reserve, which now stands at £695, 12*s.* 9*d.*

The third edition of the *Franklin-Adams Chart of the Sky* has been completed by the distribution of the third (final) section.

The Society's collection of historical books has been enriched by a copy of the first edition of Bayer's *Uranometria* (1603), presented by the late Mr. A. Stanley Williams.

We have inspected the Society's premises. The expenditure on redecoration and stair-carpets appears to be fully justified.

A list has been laid on the table containing the names of those Fellows who are still in arrear for sums due on 1938 January 1, with the amount due against each Fellow's name.

We have received from the Assistant Secretary all the information and explanations we have required.

(Signed) W. E. Candler.
F. J. Sellers.

1939 *February* 2.

GIFTS TO THE GENERAL FUNDS AND PROPERTY OF THE SOCIETY

The John Lee Gift: In 1836 John Lee, Esq., LL.D., gave the Advowson of the living of Hartwell; in 1844 he gave the Advowson of the living of Stone, Bucks. In 1879 these Advowsons were repurchased by his heir, Edward Lee, Esq., for £700.

The Lawson Bequest (1856): Henry Lawson, Esq., bequeathed to the Society the sum of £200, free of legacy duty.

The Carrington Bequest (1876): R. C. Carrington, Esq., F.R.S., bequeathed to the Society £2000 Consols.

The Lambert Bequest (1877): C. J. Lambert, Esq., presented to the Society the sum of £500, free of legacy duty, being part of a sum of money bequeathed by his father, Charles Lambert, Esq., for scientific purposes.

The McClean Bequest (1905): Frank McClean, Esq., LL.D., F.R.S., bequeathed to the Society the sum of £2000, free of legacy duty.

The Farrar Bequest (1906): The Rev. A. S. Farrar, D.D., bequeathed to the Society the sum of £100, free of legacy duty.

The Parsons Gift (1922): The Hon. Sir Charles Parsons, K.C.B., F.R.S., gave to the Society £2500 War Stock 1929–47, in memory of his father, the 3rd Earl of Rosse, who made the 6-foot reflector, and who died 1867 October 31.

The Grove-Hills Bequest (1922): Colonel E. H. Grove-Hills, C.M.G., F.R.S., bequeathed to the Society, free of legacy duty, his collection of early astronomical and mathematical books up to the year 1700, together with a sum of £250 to cover the expenses incurred by the Society in connection with the books.

The Lindemann Bequest (1931): A. F. Lindemann, Esq., bequeathed to the Society the sum of £1000, free of legacy duty.

The Archdeacon Potter Bequest (1933) (*see below*).

The Goodridge Bequest (1936) (*see below*).

The Herbert Spencer Bequest (1936) (*see below*).

The Lindley Bequest (1937): Miss Julia Lindley bequeathed to the Society the sum of £1000, free of legacy duty, which has been received from the Public Trustee in the form of £1156, 1*s.* 5*d.* Metropolitan Water Board 3 per cent. "B" Stock.

THE GROVE-HILLS SPECIAL FUND

In 1922 the Treasurer, Colonel Grove-Hills, collected by his private efforts, with the approval of the Council, a Special Fund to meet the immediate financial difficulties of the Society. The total amount received from all sources (including dividends on the investments representing the fund) has been £1913, 1*s.* 11*d.*, of which £1480, 2*s.* 10*d.* has been invested and is now represented by £535 Agricultural Mortgage 4½ per cent., £419, 17*s.* 11*d.* Conversion Loan 4½ per cent. 1940–44, and £695, 16*s.* Conversion Loan 3½ per cent. 1961.

THE HERBERT SPENCER BEQUEST

Herbert Spencer Esq., who died in 1903, nominated the Royal Astronomical Society as one of twelve Learned Societies to be eventual beneficiaries of his residuary estate. His estate was wound up in 1936, and the Society's share of the residue amounted to £1241. The conditions of acceptance of the legacy were that the sum received should be spent in certain specified ways by the Governing Body within five years of the date of payment, and might not be used in any way for purposes of endowment. The sum of £732, 11*s.* 9*d.* was temporarily invested in the purchase of £700 War Loan 3½ per cent. (the dividends being added to the value of the bequest), of which £200 stock was sold in 1938 to meet expenditure.

Receipts and Expenditure, 1936–1938 *Dec.* 31

	£	*s.*	*d.*		£	*s.*	*d.*
1936. First instalment of Bequest received May 7	500	0	0	1936. Dec. Purchase of £500 War Loan 3½ per cent.	531	13	3
1936. Second instalment received July 20 ...	400	0	0	1936. Expenditure as per 1936 Cash Account ...	276	10	7
1936. Final instalment received Nov. 4 ...	341	0	0	1936 Dec. 31. Cash Balance at Bank, carried forward	432	16	2
	£1241	0	0		£1241	0	0

	£	*s.*	*d.*		£	*s.*	*d.*
1937 Jan. 1. Cash Balance at Bank, brought forward	432	16	2	1937. Purchase of £200 War Loan 3½ per cent.	200	18	6
1937. Dividends, War Loan 3½ per cent. ...	21	0	0	1937. Cash expenditure as per 1937 Cash Account	104	7	6
				1937 Dec. 31. Cash Balance at Bank, carried forward	148	10	2
	£453	16	2		£453	16	2

	£	s.	d.		£	s.	d.
1938 Jan. 1. Cash Balance at Bank, brought forward	148	10	2	1938. Purchase of Instruments	124	7	0
1938. Dividends, War Loan 3½ per cent. ...	24	10	0	1938. Shelving, etc., for Spencer Room ...	193	5	0
1938 Nov. Sale of £200 War Loan 3½ per cent.	198	11	6	1938 Dec. 31. Cash Balance at Bank, carried forward	53	19	8
	£371	11	8		£371	11	8

	£	s.	d.
1938 Dec. 31. Balance of Fund still to be expended :—			
£500 War Stock 3½ per cent., valued at cost, as per Balance Sheet	531	13	3
Cash Balance at Bank, on deposit	53	19	8
	£585	12	11

THE ARCHDEACON POTTER FUND

The late Archdeacon Beresford Potter, who died 1931 May 10, bequeathed to the Society a 3/88th share of his residuary estate. This legacy was received in 1933, and now stands invested in £300 3½ per cent. War Stock, the cash balance of £17, 15*s.* 2*d.* being expended on the library in 1934. The Council resolved to allocate the dividends from this Fund for the purposes of the library.

	£	s.	d.		£	s.	d.
1938 Jan. 1. Balance of Fund	18	2	9	1938. Purchase and Repair of Books	9	2	0
1938. Dividends, War Stock 3½ per cent.	10	10	0	1938 Dec. 31. Balance of Fund	30	4	3
Received from Residuary Estate	10	13	6				
	£39	6	3		£39	6	3

The Goodridge Bequest (1936) : Captain J. J. L. Goodridge bequeathed to the Society the sum of £50, free of legacy duty. The Bequest has been invested in £49 War Stock 3½ per cent.

	£	s	d.		£	s.	d.
1938. Dividends, War Stock 3½ per cent.	1	14	4	1938 Dec. 31. Balance of Fund	1	14	4

TRUST FUNDS

The Lee and Janson Fund : In 1834 John Lee, Esq., LL.D., gave £100, and in 1876 T. C. Janson, Esq., bequeathed £200, the interest to be given to the widow or orphan of a deceased Fellow. These amounts now stand in £334, 10*s.* 9*d.* East Indian Railway 3 per cent. Debenture Stock.

	£	*s.*	*d.*		£	*s.*	*d.*
1938 Jan. 1. Balance of Fund	66	13	6	1938. Grants from Fund ...	22	2	0
1938 Dividends, East Indian Railway ...	7	6	10	1938 Dec. 31. Balance of Fund	54	8	4
Income Tax, 1937 April–1938 April, refunded ...	2	10	0				
	£76	10	4		£76	10	4

The Turnor Fund and the Horrocks Memorial Fund : In 1853 the Rev. Charles Turnor, M.A., bequeathed a sum of £500, which now stands in £464, 18*s.* East Indian Railway 3 per cent. Debenture Stock. In 1876 the Society received a sum of £38, 15*s.*, the unexpended balance of a fund collected for the purpose of erecting a memorial in Westminster Abbey to Jeremiah Horrocks : to this the Society added the sum of £55, 15*s.*, and the whole now stands in £103, 6*s.* East Indian Railway 3 per cent. Debenture Stock. The interest on these funds is to be used in the purchase of books for the library.

	£	*s.*	*d.*		£	*s.*	*d.*
1938 Jan. 1. Balance of Fund	8	10	9	1938. Purchase of Books ...	17	4	2
1938. Dividends, East Indian Railway ...	12	9	4	1938 Dec. 31. Balance of Fund	8	1	3
Income Tax, 1937 April–1938 April, refunded ...	4	5	4				
	£25	5	5		£25	5	5

The Harry Watson Memorial Fund : In 1920 Mrs. Watson presented to the Society the sum of £300 as a memorial to her late husband, Lieut.-Col. Harry James Watson, F.R.A.S., the interest on this sum to be used for the purchase of books for the library, such books to be indicated by a special book-plate. This gift now stands invested in £542, 18*s.* 2*d.* India 3½ per cent. Stock. In 1923 Mrs. Watson bequeathed a further sum of £958, 17*s.* to the Society, which now stands invested in £965 Agricultural Mortgage 4½ per cent. Stock. The Council resolved that these two sums should together constitute a Trust Fund, to be designated *The Harry Watson Memorial Fund*, to be used for the purchase and binding of books.

	£	s.	d.		£	s.	d.
1938 Jan. 1. Balance of Fund	30	10	0	1938. Purchase of Books ...	26	4	11
1938. Dividends, India 3½ per cent.	19	0	0	Binding	27	9	9
Dividends, Agricultural Mortgage 4½ per cent.	31	9	8	1938 Dec. 31. Balance of Fund	38	2	0
Income Tax, 1937 April–1938 April, refunded	10	17	0				
	£91	16	8		£91	16	8

The Hannah Jackson (née Gwilt) Fund : In 1861 Mrs. Hannah Jackson (*née* Gwilt) gave £300 Consols, which now stands in £309, 18*s.* 6*d.* East Indian Railway 3 per cent. Debenture Stock ; the interest to be given in medals or other awards in accordance with the terms of the Trust.

	£	s.	d.		£	s.	d.
1938 Jan. 1. Balance of Fund	50	3	2	1938. Gifts from Fund ...	50	0	0
1938. Dividends, East Indian Railway ...	6	16	0	1938 Dec. 31. Balance of Fund	9	5	6
Income Tax, 1937 April–1938 April, refunded ...	2	6	4				
	£59	5	6		£59	5	6

The George Darwin Lectureship Fund : In 1926 Sir James Jeans presented to the Society the sum of £1000 for the endowment of an annual lectureship, to be called *The George Darwin Lectureship*, the lecture to be on some subject of interest to astronomers, preference being given, in electing a lecturer, to one normally resident outside the British Isles.

This sum now stands in £1004 Consolidated 4 per cent. Loan. The income is annually applied to the purposes of the Trust in accordance with the terms of the Deed of Gift.

	£	s.	d.		£	s.	d.
1938 Jan. 1. Balance of Fund	20	1	7	1938 June. Lecture Fee	50	0	0
1938. Dividends, Consolidated 4 per cent. Loan	40	3	2	1938 Dec. 31. Balance of Fund	20	1	7
Donation from General Fund	9	16	10				
	£70	1	7		£70	1	7

The A. G. Stillhamer Trust (1937): The late A. G. Stillhamer, Esq., F.R.A.S., of Bloomington, Illinois, left all his property outright to Miss Maude S. Capps, of Bloomington; but on account of certain personal memoranda and conversation between Mr. Stillhamer and Miss Capps, the latter resolved to carry out what she believed to have been Mr. Stillhamer's wishes by the payment to the Royal Astronomical Society of the sum of 2500 dollars in cash, the conditions of acceptance being that the principal is to remain intact in the endowment fund of the Society, and the income therefrom to be used annually to pay expenses of scientific research or to purchase definite scientific instruments for use in scientific instruction or research. The Bequest has been invested in £491, 10*s*. War Stock 3½ per cent.

	£	*s*.	*d*.		£	*s*.	*d*.
1938. Dividends, War Stock 3½ per cent.	17	4	0	1938 Dec. 31. Balance of Fund	17	4	0

CELESTIAL PHOTOGRAPHS

The following have been added to the list of Celestial Photographs reproduced by the Society as slides and prints for sale to Fellows :—

R.A.S. Serial No.	Ref. No.	
502	F	57. Comet Finsler, 1937 Aug. 7–8. Blumbach, Norman Lockyer Obs. 5·5-inch Zeiss Triplet, *f.l.* 29 inches. Exp. 5 h.
503	F	58. Comet Finsler, 1937 Aug. 8–9. Blumbach, Norman Lockyer Obs. 5·5-inch Zeiss Triplet, *f.l.* 29 inches. Exp. 5 h. 21 m.
504	Q	6. N.G.C. 7662 and class F star. Wright, Lick Obs. Prismatic, direct, monochromatic images.
505	Q	7. Spectra, N.G.C. 3242, 2440. Wright, Lick Obs. 1934 Apr. 11–12 and Feb. 12–13.
506	E	94. Saturn, 1933 Aug. 6. Wright, Lick Obs. Exposures in U-V, V and Y light.
507	D	25. Moon, age 4 d. Moore and Chappell, Lick Obs. 1938 June 2. 36-inch Refractor, *f.l.* 694 inches.
508	D	26. Moon, age 7 d. Moore and Chappell, Lick Obs. 1938 May 6. 36-inch Refractor, *f.l.* 694 inches.
509	D	27. Moon, age 10 d. Moore and Chappell, Lick Obs. 1938 Jan. 11. 36-inch Refractor, *f.l.* 694 inches.
510	D	28. Moon, age 15 d. Moore and Chappell, Lick Obs. 1936 Mar. 8. 36-inch Refractor, *f.l.* 694 inches.
511	D	29. Moon, age 20 d. Moore and Chappell, Lick Obs. 1937 Oct. 24. 36-inch Refractor, *f.l.* 694 inches.
512	D	30. Moon, age 22 d. Moore and Chappell, Lick Obs. 1937 Oct. 26. 36-inch Refractor, *f.l.* 694 inches.
513	D	31. Moon, age 27 d. Perrine, Lick Obs. 1899 July 4. 36-inch Refractor, with correcting lens.
514	N	18. Spectrum of β Leporis and α Centauri. Lick Obs.

R.A.S. Serial No.	Ref. No.	
515	N 19.	Spectrum of ι Pegasi. Lick Obs. 1899 Oct. 3 and Oct. 17.
516	N 20.	Spectrum of α Herculis, 1928 Aug. 30. Lick Obs. Spectrum of α Tauri, 1927 Nov. 2.
517	M 54.	Spectrum of Saturn and Rings. Lick Obs. 1937 Sept. 13.
518	I 9A.	N.G.C. 1976. Great Nebula in Orion. Lick Obs. 1898 Nov. 16, 1928 Mar. 19. Crossley Reflector, *f.l.* 210 inches.
519	I 8A.	N.G.C. 1976, 1977. Great Nebula in Orion. Mayall, Lick Obs. 1938 Feb. 25. Crossley Reflector, *f.l.* 210 inches.

PUBLICATIONS OF THE SOCIETY

During the past year the Society has published *Monthly Notices*, vol. 98; *Geophysical Supplements*, vol. 4, Nos. 4 and 5; *Memoirs*, vol. 66, pt. 1; *Occasional Notes*, Nos. 1 and 2; and *Franklin-Adams Chart of the Sky*, 3rd edition, Section 3.

The Council regret that they have to record the loss by death of the following Fellows and Associates during the past year :—

Fellows : John Alexander Armstrong
H. Glanville Barnacle
A. de la Baume Pluvinel
David Baxandall
C. H. Brewitt-Taylor
Ernest William Brown
Reginald Henry Consterdine
Herbert E. Purey Cust
Percy L. H. Davis
Joseph Edward Evans
Walter Goodacre
*George Ellery Hale
Elijah Howarth
Francis G. Pease
John William Robinson Punch
Alexander William Roberts
Arthur Stanley Williams

Associates : William Wallace Campbell
Anders Severin Donner
*George Ellery Hale
William Henry Pickering

JOHN ALEXANDER ARMSTRONG was born in Dublin in 1880 and educated at Wesley College.

He was trained as an electrical engineer and later on entered the motor business.

As a young man he was very interested in practical optical work and made a number of mirrors and object-glasses.

He entered the works of Sir Howard Grubb & Sons Ltd. in Dublin about 1915 and in 1916 was put in charge of the optical shops, which at that time were employing about 100 hands on the manufacture of optical components for submarine periscopes and gun-sighting telescopes.

His chief contribution to astronomy was his work on manufacturing the optical parts for a number of large telescopes.

The Grubb works were transferred to St. Albans in 1920, and while there Armstrong worked the 40-inch mirror for the Simeis reflector and the objective for the 26½-inch Johannesburg refractor, under the guidance of the late Sir Howard Grubb.

* Fellow and Associate.

When the late Sir Charles A. Parsons took over the firm in 1925 and established the firm of Sir Howard Grubb, Parsons & Co., Armstrong was put in charge of the optical department at the new works at Newcastle-on-Tyne, where he was entirely responsible for the working and figuring of the optical components for the 36-inch Edinburgh, 40-inch Stockholm, 36-inch Greenwich and 72-inch Toronto reflectors, the 24-inch Santiago and 24-inch plus 20-inch Stockholm refractors, two 40-cms. three lens objectives for the Leiden-Johannesburg Astrograph and one of 33-cm. aperture for the Marshall Pilsudski Memorial Observatory, Mount Rozspiewany, Poland.

Mention might also be made of a number of fused quartz mirrors for the new solar telescope at the University Observatory, Oxford.

Armstrong was an artist at his work and would not allow any mirrors or lenses to pass out of his hands until he was quite satisfied with their performance.

He died at his home at Monkseaton on November 25 and leaves a widow and two young sons.

He was elected a Fellow of the Society on 1927 April 8.

C. YOUNG.

HENRY GLANVILLE BARNACLE died in Subiaco, W. Australia, on 1938 August 24 at the age of eighty-nine. As a young man he was on the staff of the Royal Observatory, and in Airy's Report to the Board of Visitors for 1874 he is mentioned as a member of one of the expeditions sent to the Pacific to observe the transit of Venus of that year, as well as the donor of a telescope for this expedition. On his return he resigned his post at the Observatory, and entered St. John's College, Cambridge, After taking his M.A. degree he was ordained a priest in 1879. In 1911, after a period as Vicar of Holmes Chapel, Cheshire, he moved to Australia where he became Rector of Rosalie, Perth. He is survived by his widow, two sons and four daughters, one son having been killed in the War. He was elected a Fellow of the Society on 1874 May 8, and was one of the foundation members of the West Australian Astronomical Society.

AYMAR DE LA BAUME PLUVINEL. In the death of Comte de la Baume Pluvinel, France and the whole astronomical world have lost a great amateur astronomer whose work and career were in many ways unique. More fortunate than many amateurs in that he was free to give the greater part of his time to astronomical research, he used that freedom to work in the closest collaboration with and to the great profit of professional astronomers.

His astronomical career commenced at the age of twenty-two when he took part in the expedition to Haiti to observe the transit of Venus of 1882. He appears to have been in no small measure responsible for the use on this expedition of the then just introduced commercial silver bromide plate, and many of his plates were measured and used for the determination of the solar

parallax. On his return from this expedition de la Baume Pluvinel joined the staff of the observatory at Meudon, then under the direction of Janssen, as a volunteer, and played an important part in French expeditions to observe the eclipses of 1889, 1890, 1893, 1900, 1901, 1905, 1912, 1914 and 1932. As a result of the expedition to Crete he became interested in the origin of the oxygen B band in the solar spectrum, and was able to show, in part from spectra obtained on Mt. Blanc in 1898, and in part from a spectrum obtained in 1899 from a sounding balloon at a height of 9000 m., that the band was unquestionably of telluric origin. This appears to have been the first time that a spectrograph complete with a clock-driven mirror for reflecting the solar light into the slit was successfully sent up with a sounding balloon, and it is an interesting example of that skill and manual dexterity which characterized all of de la Baume Pluvinel's work. In addition to this work, and to his studies of the theory of the photographic process, he was also a pioneer in the study of cometary spectra by means of the objective prism. His first spectrum was obtained in 1902, while in 1907 in collaboration with Baldet he obtained a spectrum of Daniel's comet which led to the identification of the red cyanogen bands. Similarly, in the spectrum of Comet Morehouse were found for the first time those doublets subsequently identified by Fowler as due to CO^+. In quite a different field, that of positional astronomy, de la Baume Pluvinel also made significant contributions. He was the inventor of the *lunette coudée*, an instrument for the determination of latitude and time by the equal altitude method. This instrument, which appears to possess several advantages over the prismatic astrolabe, was used at the Paris Observatory in the world longitude programme of 1933 November.

It was only fitting that such contributions should receive official recognition. de la Baume Pluvinel was awarded the Janssen prize in 1902 and the Valz prize in 1909, while in 1932 he was elected a member of the Académie des Sciences in the section of astronomy. He was elected a Fellow of the Society on 1895 February 8.

DAVID BAXANDALL was a leading authority on the work of the early makers of scientific instruments. His death on 1938 January was the more regrettable because much of the material which he had collected on this subject still remains unpublished. A permanent monument to his work remains, however, in the Science Museum, for the remarkable collection of early astronomical, optical and mathematical instruments there established is largely the result of his efforts. Born on 1874 April 9 at Haworth, near Keighley, he proceeded at the age of seventeen to the Royal College of Science with a Royal Scholarship. After obtaining his associateship he worked on with Lockyer at the College until 1898, when he entered the Science Museum. Here he remained until his retirement in 1934, gradually rising to the post of deputy keeper in charge of the Science Division. Of a modest and retiring disposition, Baxandall was admired and respected by all who had the privilege of knowing him. He is survived by his widow and two sons. He was elected a Fellow of the Society on 1912 January 12.

CHARLES HENRY BREWITT-TAYLOR, late Commissioner to the Chinese Customs service, died on 1938 March 4 at his residence, Cathay, Earlsferry, Fife, aged eighty years. He was born at Kingston, Sussex, 1857 December 11, and spent most of his active life in China. For many years he resided at Foochow and taught navigation and astronomy at the Imperial Arsenal there. During the hostilities of 1884–5 his house was wrecked in the bombardment by the French fleet. In 1891 he was appointed to the Imperial Maritime Customs, being afterwards attached to the Chinese Post Office ; while Postmaster at Shanghai he was responsible for the building of the new Post Office. He was in Peking during the siege of the Legations in the Boxer rising of 1900, when his translation of a long Chinese novel was destroyed and had subsequently to be rewritten. He published a work on *Problems and Theorems in Navigation and Nautical Astronomy*, and edited and enlarged a second edition of F. Hirth's *Textbook of Modern Documentary Chinese* ; in addition he made various translations from the Chinese, including the novel in two volumes mentioned above, entitled *San Kuo, or Romance of the Three Kingdoms*.

He married, first, Alice Mary Vale, who died in 1891, and by whom he had two sons, both of whom predeceased him, one being killed in the Great War ; and secondly, Ann Michie, of Tientsin, who survives him with two daughters.

He was elected a Fellow of the Society on 1885 May 8.

ERNEST WILLIAM BROWN was born on 1866 November 29, in Hill, England, son of William and Emma Martin Brown. He had two sisters, one of whom survives him ; his only brother died in infancy. His father was a well-to-do farmer.

During his school years at East Riding College, Hull, he showed such aptitude for mathematics that it was decided he should continue his training at Cambridge University, where he entered Christ's College. Brown's years at Cambridge were happy ones ; he succeeded in finding the proper balance between the intellectual and the social side of college life. The one sport that he indulged in was rowing. The Christ's College Boat Club figured prominently among the treasured reminiscences of his college years.

Beyond question the Cambridge professor to whom he was attached more than to anyone else was G. H. Darwin. The attraction was mutual, and grew into a friendship that continued until Darwin's death in 1912. It was Darwin who suggested to him the study of Hill's papers on the lunar theory. This was in the summer of 1888, after Brown had spent a year of post-graduate study at Cambridge. At that time Darwin himself had not yet made a thorough study of Hill's researches.

It is not unusual that the recommendation to an advanced student of a subject for specialized study gives a young man a start on a successful scientific career in the suggested field, but Brown's case is one of the most striking on record. From the summer of 1888 on, until his death, he studied the lunar theory. For twenty years he gave very little thought to other research. During the remaining thirty years, although he had then

broadened his field of activity, the Moon's motion remained his favourite subject, to which he returned again and again.

He remained in Cambridge, as fellow of Christ's College after 1889, and received his M.A. degree in 1891. In that year he went to the United States and became instructor in mathematics in Haverford College. His connections with his Alma Mater remained very intimate. A part of almost every summer was spent at Cambridge, frequently as guest at the Darwin residence, even long after Darwin's death. He received his Sc.D. degree in 1897, and became honorary fellow of Christ's College in 1911.

The study of the Moon's motion was not undertaken with the ambitious plan of creating a new and complete lunar theory. This plan grew gradually as he studied the entire field, and familiarized himself with the various methods that had been used or were available. Two methods attracted him particularly, Hill's and Delaunay's. He learned to know the value and the power of Hill's method by actual application and further developments. Beginning in 1891 he published a number of contributions in which he presented the theoretical developments required for evaluation of certain classes of terms in the Moon's motion and their numerical application.

The long period of preparation was followed by three years, 1895 to 1897, of astonishing productivity. In this short space of time he published (1) *Investigations in the Lunar Theory*, in which a complete plan was presented for the development of the solution of the "main problem"; (2) *An Introductory Treatise on the Lunar Theory*; (3) important theoretical papers including a theory of the secular accelerations in the Moon's motion; and (4) the first part of his *Theory of the Motion of the Moon.*

An Introductory Treatise on the Lunar Theory shows how completely he had absorbed the entire subject, the more remarkable if one considers that the author had not yet reached the age of thirty.

Brown himself considered his evaluation of the secular accelerations (1896–97) his favourite contribution to celestial mechanics. For this reason it deserves a somewhat detailed presentation.

The theoretical determination of the secular accelerations, produced by the secular diminution of the eccentricity of the Earth's orbit, had been among the most difficult and laborious parts of the lunar theory. Newcomb, in 1895, showed that the derivation could be rendered a relatively simple matter by making use of a remarkable theorem that may be stated as follows: If the Delaunay variables L, G, H of the "main problem" are expressed in terms of the constants n, e, γ, e', the variations of n, e, γ can be obtained from those in e' by the relation

$$\delta L = \delta G = \delta H = 0,$$

where

$$\delta = \delta n \frac{\partial}{\partial n} + \delta e \frac{\partial}{\partial e} + \delta \gamma \frac{\partial}{\partial \gamma} + \delta e' \frac{\partial}{\partial e'}.$$

If π_1, θ_1 are the mean motions of the perigee and node, similarly expressed in terms of n, e, γ, e', the secular accelerations are obtained from

$$\int \delta n dt, \qquad \int \delta \pi_1 dt, \qquad \int \delta \theta_1 dt.$$

Newcomb's evaluation still suffered from the slow convergence of Delaunay's developments. On that account his result for the secular acceleration in the Moon's mean longitude was uncertain to about one-twentieth of its amount. Brown showed that a new theorem, related to Newcomb's, could be used to obtain the three secular accelerations each to one three-hundredth part, not including the uncertainty present in $\delta e'$ on account of the uncertainties in the planetary masses.

The fundamental relation, in which the unimportant terms depending on $(a/a')^2$ are ignored, is :

$$(L-G)\delta\frac{\partial\pi_1}{\partial\alpha}+(G-H)\delta\frac{\partial\theta_1}{\partial\alpha}=-\frac{3}{2}(E+M)\delta\frac{\partial}{\partial\alpha}\left(\frac{1}{r}\right)_0,$$

in which $\alpha=n$, e, γ successively, and $(1/r)_0$ is the constant part of the final trigonometric development of $1/r$. The symbol δ has the same meaning as in Newcomb's theorem. As a special case, since $(1/r)_0$ does not contain the first powers of e^2, γ^2, the part of δn that depends on n'/n and $\delta e'$ only is obtained from

$$\frac{\partial^2}{\partial n^2}\left(\frac{1}{r}\right)_0\delta n=-\frac{\partial^2}{\partial n\partial e'}\left(\frac{1}{r}\right)_0\delta e'.$$

The numerical work was carried out with a judicious use of both Delaunay's expressions and the results obtained in his own theory in which the Moon's mean motion had received a numerical value.

The systematic development of the lunar theory began in 1895. The entire plan had been so well prepared that the work could proceed without serious interruptions by unforeseen difficulties. The results were published in five parts in the *Memoirs of the Royal Astronomical Society*, 1897 to 1908. The fourth part, 1905, concluded with a tabulation of the final coefficients of the solution of the "main problem." Both as to completeness and accuracy Brown's solution surpassed those of his predecessors in a remarkable degree. Few terms having coefficients in longitude and in latitude exceeding $''\cdot001$ were not obtained, and in the great majority of terms the uncertainty did not exceed $''\cdot001$. In Hansen's theory some coefficients were in error by some tenths of a second of arc ; Delaunay's theory, on account of the slow convergence peculiar to his development, contained a few terms that were in error by as much as a whole second of arc.

Brown was always ready to give Hill a proper share of the credit for his solution of the main problem. It would be unfair, however, to consider his work merely a routine application of Hill's methods. This would have been impossible for a man of his character. He could use ideas of others, but would rarely apply them without important modifications. As a rule such modifications would be designed to shorten the work. This is very particularly true of the modifications to Hill's plan in the elaboration of the lunar theory. The study of this theory is complicated by the numerous devices and changes in procedure introduced for this purpose. The entire work had been completed with the aid of only one computer, Mr. Ira I. Sterner, A.M.

A difficult task remained after the work on the main problem had been completed, namely, the evaluation of the effects upon the Moon's motion due to the attractions of the planets and the deviations from sphericity of the Earth and the Moon. In 1878 Newcomb published his comparison of observations of occultations with Hansen's theory, extending backward to 1620 the period during which the Moon's motion was known with a fair degree of accuracy. This established more firmly than before the fact that large unexplained differences remained between Hansen's theory and observations. The question whether these differences could be ascribed to imperfections of the gravitational theory thus became one of the most pressing problems in gravitational astronomy, a problem that could be solved only by a reliable determination of the planetary perturbations in the Moon's motion. Brown's evaluation of these perturbations provided the answer, and established beyond reasonable doubt that the Moon's observed motion cannot be accounted for by gravitational theory alone. The fifth and final part of this theory, published in 1908, contained his results. The direct planetary perturbations had been published separately in more detail as an "Essay which obtained the Adams Prize in the University of Cambridge for the year 1907." This fifth part of the lunar theory is, in many respects, Brown's most original work. No other problem in celestial mechanics requires a more careful handling of the equations of motion and of the complicated developments. Brown's ability in treating such a problem has never been equalled. The planetary perturbations on the Moon had been developed fifteen years earlier by Radau and, just when Brown finished his work, a memoir by Newcomb appeared which contained a solution of the same problem. Later Brown published a comparison of the three results, leaving very few of the differences unexplained.

The construction of new lunar tables was undertaken as soon as the theory had been completed. Brown had been connected with Haverford College since 1891, first as instructor and since 1893 as professor of mathematics. In 1907 he became professor of mathematics in Yale University, just when it became desirable to find ways and means for the construction of the tables. An agreement was made by which Yale University undertook the cost of their calculation, printing, and publication. This involved a sum of some thirty-four thousand dollars.

As with his work on the theory, he did not start the definitive calculations for the tables without an exhaustive study of the problem before him. It is not likely that he had, at that time, more than a superficial knowledge of the construction of astronomical tables. When he had completed the task he had made some very real contributions to the subject. The excellence of the tables is, to a large extent, due to the efficient assistance rendered by Dr. H. B. Hedrick who was employed as chief computer for nine years. Hedrick had been connected with the Nautical Almanac office in Washington for twenty-four years, and possessed exceptional qualities as computer in the highest sense.

The most ingenious new feature of the tables is the arrangement of the single-entry tables. Here the improvement over Hansen's form of tabula-

tion is extraordinary. The tables cover less space than in Hansen's case, and are more convenient to use. This is especially due to their being completely re-entrant, *i.e.* after the value of the argument for a certain instant has been found, the values for succeeding half-day intervals for a whole year can be found without recomputation of the argument or change of the interpolating factor.

The monumental *Tables of the Motion of the Moon* were published by the Yale University Press in 1919; they had been printed at the Cambridge University Press. The three volumes, containing some 660 pages of tables and explanation of their use, set a standard of perfection for works of this nature that will not easily be surpassed.

The numerical values for the constants used in the tables had been obtained from a comparison with the Greenwich observations in the years 1750 to 1900. This mass of some 20,000 observations had been prepared and analysed by Cowell, a continuation and extension of an undertaking started by Airy. The accuracy of the constants is, therefore, primarily due to Cowell's admirable analysis. An interesting confirmation was obtained in 1932 by Spencer Jones who, in a revision of Newcomb's occultation work, made an independent determination of the constants from totally different material, and derived results that are in excellent agreement with Brown's values.

The new tables have been used for the calculation of the Moon's place in most national ephemerides since 1923. The great improvement over Hansen, especially in the short-period terms, is immediately apparent from the small range of the residuals from observations in any one year. The new theory did not, however, account for the large fluctuations in the Moon's mean longitude that had puzzled Newcomb; a "great empirical term" was introduced with coefficient $10''.71$ and period 257 years in order to eliminate the major part of the fluctuations during the past few centuries. Newcomb had seen very clearly that the discrepancy in the Moon's motion might be due to irregularities in the rate of rotation of the Earth. In that case similar fluctuations should be present in the observed mean longitudes of other bodies in the solar system. Newcomb concentrated upon transits of Mercury and found some indication of agreement with the Moon, but not enough to be quite convinced of its reality. Brown gave much thought to this problem, especially after 1913. Finally, in 1926, he published his well-known paper: "The Evidence for Changes in the Rate of Rotation of the Earth and their Geophysical Consequences," in which he accepted the explanation that the fluctuations in the Moon's mean longitude, including the great empirical term, were caused by irregular changes in the Earth's rate of rotation. His argument was that no external cause had been found for such effects in the Moon's motion, and that the explanation was supported by a general similarity between the residuals in the Sun's longitude and those exhibited by the Moon. The principal value of this paper was the clear exposition of the entire problem. Other astronomers had helped to clear the ground for Brown's contribution. Especially noteworthy was Innes's discussion in 1925, in which he concluded, mainly from a study of transits of

Mercury : "When allowance is made for the variability of the rotation of the Earth, the Moon's motion will probably be found to be purely gravitational. The inclusion of empirical terms confuses." Neither Innes's nor Brown's exposition could be considered a complete proof of the irregular variability of the Earth's rotation. This required the more thorough quantitative analysis of all relevant observational data which was subsequently made by other astronomers, mainly by de Sitter and by Spencer Jones, and which proved that the problem was more complicated than Innes or Brown had assumed.

From 1926 on Brown gave much attention to comparisons of observations of the Moon with the tables. This led to his occultation campaign, supported by many astronomers all over the world. These discussions meant a great deal to him : they kept him occupied at times when his failing health did not permit him to do more strenuous work.

He found several opportunities to apply his knowledge of the theory of the Moon's motion to the study of related problems. After a discussion with Jackson, who had developed a plan to apply Delaunay's theory to the motion of the eighth satellite of Jupiter, Brown took up this problem. He overcame the extremely slow convergence by ingenious extrapolations, but was apparently not satisfied with the results. Soon afterwards he began an entirely numerical development of the theory by a totally different method.

During the last three years of his life the main problem of the lunar theory again held his almost exclusive attention. In this period he treated the stellar case of the problem of three bodies, and followed with the greatest interest the numerical verification of the solar perturbations in the Moon's motion by his former pupil, Dr. W. J. Eckert, who had undertaken this work at Brown's suggestion.

He ventured but rarely outside of the realm of celestial mechanics. Next to the lunar theory he was attracted primarily to the problems of planetary motion. Until 1908, when he finished the lunar theory, his explorations in this field had always been closely connected with the study of the Moon's motion. From then on they became independent. A theoretical study of the motion of bodies near the Lagrangian triangular points was later followed by a general theory applicable to all planets of the Trojan Group, and particularly to orbits with large amplitudes of libration. Soon after his earlier work on this problem (1910) he began a more general study of resonance in planetary motion. This problem, related to that of the gaps in the ring of asteroids, had been treated on numerous previous occasions by many mathematical astronomers. Brown's contributions had many original features ; he was probably the first to see clearly that "the calculus of probabilities is more likely to lead to further information than the logical processes of analysis."

The more abstract phases of celestial mechanics could hold his attention for limited times only. Gradually he became more particularly interested in the study of practical methods for planetary theories. In this connection he dealt extensively with the development of the disturbing function. This

led eventually to the construction of the *Tables for the Development of the Disturbing Function* (1933).

He concentrated upon two different forms of planetary theories: the variation of arbitrary constants, and a method in which a modified true orbital longitude is used as independent variable. In the former he limited himself mainly to the indication of abbreviated methods and to the computation of the most important terms of higher order due to the presence of small divisors. His true-longitude method is a modification of Laplace's method. It is not an easy matter to judge its value. Brown used it himself in its original form in the theory of the Trojan Group because it offered some advantages in obtaining the intermediate orbit. Later he decided that for the Trojan Group the method of the variation of arbitrary constants is superior. He used it again in the theory of the eighth satellite of Jupiter. In the introduction to the second part of this theory he wrote: "The method has given rise to complications which make the developments of the terms of higher order difficult to follow, requiring great care if errors are to be avoided." A complete application to an ordinary planetary theory has not yet been made.

In the treatise *Planetary Theory* (1933), written in collaboration with Dr. C. A. Shook, a coherent presentation is given of most of his contributions to celestial mechanics that are not related to the lunar theory.

Striking features of all his published work are the clearness of presentation, the orderly development of the subject, and the excellent command of the English language. This suggests that he could have been a great teacher. He was, in fact, able to present a difficult subject to any audience with perfect lucidity. However, he never permitted himself to become fond of teaching, although he fulfilled his teaching duties conscientiously. He taught various subjects in pure and applied mathematics, in later years only dynamics and celestial mechanics.

Brown's high standing among scientists was recognized early. He became a member of numerous honorary societies and received the highest distinctions. At the very early age of thirty-one he was elected Fellow of the Royal Society; he received the Royal Medal of the Society in 1914. In 1907 the Royal Astronomical Society awarded him the Gold Medal for his researches in the lunar theory. Then followed the Pontécoulant Prize of the Paris Academy of Sciences in 1910, and the Bruce Medal of the Astronomical Society of the Pacific in 1920. After he had become an American citizen he was elected member of the National Academy of Sciences. The Watson Medal, presented to him by the Academy in 1937, was among his most cherished honours: perhaps because it was awarded specifically not for his lunar theory but for his other contributions to celestial mechanics.

He was never married and made his home with his unmarried younger sister, who predeceased him by about two years. No man could ever have asked for a more devoted companion than he had in his sister; she seemed to concern herself exclusively with his comfort. He was an accomplished piano player, fond of music. He played a good game of chess and read widely. His literary taste changed with his age from a fondness for English

classics to a preference for detective stories. In his youth he was an enthusiastic mountain climber, and he was always fond of travelling. Attendance on scientific meetings was, as a rule, a good enough excuse for making shorter or longer trips. He enjoyed these meetings principally because they gave him opportunities to meet the many friends that he counted among his colleagues.

For many years he suffered from bronchial troubles. The attacks became more severe as he grew older, and his early retirement in 1932 was partly on account of this ailment. His six years of retirement were clouded by these ever-returning struggles for health. Notwithstanding this he kept remarkably active and cheerful, and saw to it that scientific work did not interfere too much with pleasure. In the spring of 1938 his sufferings increased, he grew weaker as his condition became more serious, and he died in New Haven, Connecticut, on 1938 July 22. He had been a Fellow of the Royal Astronomical Society since 1889 January 11.

DIRK BROUWER.

REGINALD HENRY CONSTERDINE was born on 1862 November 5 at Alderley Edge Vicarage, built by his father, the Rev. J. W. Consterdine, who lived there for fifty-two years. The son took his B.A. at Cambridge (Trinity College) in 1885 and his M.A. in 1902 ; he was ordained in 1886. He became a missionary in Japan and spent many years of his life there, where his kindly character and deep faith greatly endeared him to his flock and fellow-workers. He gave himself unstintingly to his vocation, and his unremitting work combined with the climate to affect his health ; after a period of leave he was considered unfit to return to Japan, and was appointed vicar of Lindlow, Cheshire. Here he worked till his retirement in 1937, when he went to live at Wilmslow, and died there on 1938 August 4. All his life he had taken a deep interest in astronomy, and while a missionary in Japan he used his telescope to foster the interest of other people in his favourite hobby. While at Lindow he became the possessor of a $5\frac{1}{2}$-inch refractor by Cooke, given to him by a former vicar of Cheltenham, and it was his greatest delight to use this for the entertainment of his friends. A long felt ambition of his was fulfilled when he was elected a Fellow of the Society on 1938 January 14, only a few months before his sudden death from heart trouble.

HERBERT PUREY CUST died at his home at Highgate on November 11 last, after a mercifully short illness. He had been a Fellow of the R.A.S. since 1910. He will best be known as Hydrographer of the Navy, which important post he held from 1909 August 31 to 1914 August 31.

Herbert Edward Purey Cust was the second son of the Very Rev. Arthur P. Purey Cust, D.D., Dean of York, and Lady Emma, daughter of the fifth Earl of Darnley, and a great-grandson of the first Lord Brownlow. Born on 1857 February 26, he entered the Royal Navy in 1870, being promoted to Sub-Lieutenant in 1876 and Lieutenant in 1878 (being promoted to that

rank whilst serving in the Royal Yacht). Later he elected to specialise in Hydrographical Surveying and received his first appointment in that branch of the Navy on 1881 January 1, joining H.M.S. *Fawn* on Surveying Duties in the Red Sea. He was continuously employed afloat on Surveying Duties in various surveying ships, being promoted to Commander in 1894 June after two years in his first command in H.M.S. *Dart* and in Charge of Survey. He served as Naval Assistant to the Hydrographer until 1897 November, being then appointed afloat again, in Charge of Survey, to H.M.S. *Rambler*, serving both on the North American and South African Stations. He was promoted to Post Captain in 1900 December and in that rank commanded H.M. Surveying Ship *Triton* in Home Waters.

It was in 1907 that Captain Purey Cust was chosen for the post of Assistant Hydrographer and in 1909 August he succeeded Admiral Sir Mostyn Field, K.C.B., F.R.S., as Hydrographer and for five years he held that important and responsible office. Although Purey Cust was promoted to Rear-Admiral, placed on the retired list in 1912 and was succeeded as Hydrographer in 1914 August, he was not at all willing to sever his connection afloat with the Service which he had served so well, and consequently after a request to the Board of Admiralty he was again given Active Service, discarding his naval rank, and obtaining a commission in the Royal Naval Reserve as Captain, dated 1914 November 16. In this capacity he commanded the *Zaria*, a Mercantile Fleet Auxiliary based on Scapa Flow, and carried out valuable service in connection with supplies to the Fleet. During the latter part of the War he held the rank of Commodore, R.N.R., being finally "paid off" on 1919 May 5 after just under forty-nine years in the Naval Service of his country.

Admiral Sir Herbert Purey Cust saw war service during the naval and military operations in the Eastern Sudan and was awarded the Egyptian medal and Khedive's Bronze Star, 1884–85. Later he received the South African medal when serving in command of H.M.S. *Rambler* during 1900 on that station, and also in 1918 medals for services in the Great War. He was made C.B. in King George's Coronation List 1911, and received the K.B.E. in 1919.

As an example of his exceptional skill and ability, he obtained first prize of £100 for General Proficiency at the R.N. College, Greenwich, in 1884.

Subsequently his career as a Hydrographic Surveyor was most successful, culminating as it did in his being appointed as Hydrographer of the Navy in 1909.

The following were amongst those items which Admiral Sir Herbert Purey Cust designed, some of which are still in use in H.M. Surveying Service :—

(1) Star Chart for facilitating the Selection of pairs of Stars for Observations for Latitude (1897).
(2) Tables for facilitating the Calculation of Heights (1895).
(3) Cust's Rolling Protractor.
(4) Cust's Station Pointer.
(5) Cust's Vacuum Tide Gauge.

In 1895 he married Alice Ella, eldest daughter of the late Mr. George Stuart Hepburn, of Smeaton, Australia, and had one son and one daughter. The former, Sub-Lieutenant Arthur John Purey Cust, gave his life in the War.

H. P. DOUGLAS.

PERCY LYALL HOOKER DAVIS was born on 1850 September 1 in Ireland, where his father, a captain in the Royal Navy, was stationed. He received his education at the Royal Naval School, then carried on where the Goldsmiths' Institute, New Cross, is now established. At the age of eighteen he entered the Nautical Almanac Office, where he remained until he retired in 1916, after having reached the position of Chief Assistant. He married in 1887, and had three children, of whom two survive. He lost his wife in 1916. Nearly all his adult life was spent at 95 Cranfield Road, Brockley, S.E., where he died on 1938 March 11.

All through his official career Mr. Davis showed a keen interest in the calculations appertaining to the *Nautical Almanac* and especially in "Lunars," at one time an important section of the *Almanac*. Many improvements in office methods were due to him.

Apart from this, his greatest interest lay in the publication of his numerous nautical tables. In his early years he collaborated with his father, and he also revised and extended the work of Captain John Burdwood, a colleague of his father at the Admiralty.

There is space to name only a few of the Tables that bear his name, such as "Sun's True Bearing and Azimuth Tables," "Chronometer Tables," "Alt-Azimuth Tables," "Ex-Meridian Tables and Supplementary Azimuths." His "Star Azimuth Tables" followed on the very general adoption of stellar observation as a means of navigation and supplied the seaman with the same details regarding stars as he could get from "Burdwood & Davis" for the Sun. His "High Latitude Tables" between 61° and 78° were prepared for and used by the Antarctic Expedition of 1901. He also published *Requisite Tables* (*Logarithmic*) to five places of decimals for practical sea work. This book also contains a Table of Logarithmic and Natural Haversines, specially designed for navigation as it then was (1905). His *Five-Figure Logs and Anti-Logs*, also issued in 1905, was specially prepared for actuarial and general calculation.

Mr. Davis's principal recreation was boating, and he was well known on the upper reaches of the river. He was also extremely skilful in, and had a taste for, all forms of "handywork." In addition to this he was a member of the South London Musical Club, possessing an excellent bass voice, and as a young man he sang in the presence of Queen Victoria.

Unfortunately he suffered from a physical defect causing lameness, otherwise he would no doubt have climbed high in H.M. Navy had his career been directed thereto.

Mr. Davis was generous, almost to a fault, and he was always ready to give advice and assistance. He had many an amusing tale to tell of the early history of the office, and the men who "figured" there.

He became a Fellow of the Society on 1875 May 14.

W. F. DOAK.

JOSEPH EDWARD EVANS was born 1855 September 18, being the son of Lieut. Evans, R.N., who was in charge of the Coastguard at Robin Hood Bay. At the age of eleven he entered the Royal Hospital School at Greenwich, of which the Rev. James Hill, D.D., was then headmaster. He there became acquainted with Thomas Lewis, also a boy at the school, and a close, lifelong friendship ensued. As a boy at school he was remarkable for his extraordinary powers of concentration, which enabled him to read a page of his lessons once, close the book, and when the time came never fail to answer correctly the questions asked of him. At the end of his school career Evans remained for some time at the Royal Hospital School as a pupil teacher, and later on took his B.A. degree at London University. In 1880 he went to India, having been appointed the first Principal of the Dindigul Training College for Hindus. On the closing of the College in 1890 Evans returned to England and occupied various teaching posts. In October 1899 the headmastership of the Royal Hospital School fell vacant and Evans was appointed to fill the post, thus becoming head of the school he had entered as a boy thirty years before. For twenty-one years he remained headmaster, retiring in September 1920.

In collaboration with E. W. Maunder he contributed a paper to the *Monthly Notices* (63, 488, 1903), "Experiments as to the Actuality of the 'Canals' of Mars." As the result of experiments made with boys of the Royal Hospital School, the authors concluded that "in the majority of cases they (the *canals*) are simply the integration by the eye of minute details too small to be separately and distinctly defined."

In 1879 Evans married Alice Mary Davies, daughter of the Rev. Benjamin Davies of Greenwich. Mrs. Evans predeceased him in 1935, and they are survived by three sons and three daughters. Evans died on the morning of Christmas Day, 1938, at the age of eighty-three years. He was an earnest Freemason and a kindly man. Amongst the last words he said to the writer, not long before his death, were these : "Do all the kindnesses you can and then go." And thus he seemed to sum up his outlook on life.

He was elected a Fellow of the Society on 1886 January 8.

P. J. MELOTTE.

WALTER GOODACRE was born at Loughborough in 1856. When he was about seven years old, his father came to live at Finsbury Park, and established in London the firm of William Goodacre & Sons, matting and carpet merchants and manufacturers.

On leaving school, Goodacre entered his father's business, and in due course became head of the firm. His interest in astronomy dated from his schooldays, and when he was still a young man he began to specialise in lunar work, joining the Liverpool Astronomical Society. Later he became Director of that Society's Lunar Section. He became an original member of the British Astronomical Association on its foundation in 1890, and, in 1897, succeeded Thomas Gwyn Elger as Director of the Lunar Section of the Association. This post he held for forty years, resigning only a year before his death.

He was throughout his life a keen observer. His first large telescope, with which he did most work, was a 12-inch Calver reflector. After the War, when he lived at Finchley, he replaced this with an 18-inch equatorial reflector by the same maker; after using this for a few years, he finally purchased a refractor by Cooke, of 10 inches aperture. This instrument, acquired a few years before his retirement from business in 1929, he took with him then to Bournemouth, where he spent the remaining part of his life.

Apart from his helpful Directorship of the Lunar Sections of the L.A.S. and B.A.A., there can be no doubt that Goodacre's most useful contribution to astronomy was his great Lunar Map, published in 1910. This map was originally drawn on a scale of 77 inches to the Moon's diameter, but the scale was reduced to 60 inches on publication. As regards the positions of the features recorded on it, these were based on 1433 points measured by the late S. A. Saunder. The details were filled in partly from photographs and partly from visual observations made by himself and others. The map has proved of great value to many lunar workers, in this and other countries.

In 1932 he published his book *The Moon*, which contains a reproduction of the large map on a smaller scale, together with much valuable data collected by the author in the course of his long observing career.

Goodacre served as President of the British Astronomical Association in the years 1922–1924, and in 1928 founded for the Association the Medal and Gift that are associated with his name.

In 1883 he married Frances Elizabeth Evison. She died in 1910, but the two children of the marriage, a son and daughter, survive him. Walter Goodacre himself died in Bournemouth on 1938 May 1 in the eighty-third year of his age. He was elected a Fellow of the Society on 1885 January 9.

W. H. STEAVENSON.

ELIJAH HOWARTH was a Fellow of the Society for many years, having been elected on 1881 January 14. He was born at Liverpool in 1853 and died at Dronfield, Derbyshire, on 1938 April 1. His two main interests in life were art and science, and during his long life he travelled extensively, and had the good fortune to witness two total eclipses of the Sun. His interest in astronomy dated from Cambridge days, where he studied under J. C. Adams, his sponsor for Fellowship of the Society. From 1871 to 1876 Howarth was an assistant at the Liverpool Museum, and was then appointed to the Curatorship of Public Museums in Sheffield, a post he held until 1928. He was also Curator of the Mappin Art Gallery, Sheffield, from its commencement in 1887, while the observatory in Weston Park was also in his charge for many years. He was one of the founders of the Museums Association and acted as its secretary from 1891 to 1909, and as President from 1912–13. He edited the *Museums Journal* from 1091 to 1909.

Howarth was a member of the Advisory Council of the Board of Education from 1912–20, and lectured widely on art and scientific subjects. He also issued meteorological reports for Sheffield and district for over fifty years. He was twice married and had two sons and five daughters. He was a prominent Freemason.

FRANCIS G. PEASE made probably his greatest contribution to astronomy in the design of telescopes. Trained as a mechanical engineer at the Armour Institute of Technology in Chicago, he in 1901 became a member of the staff of the Yerkes Observatory where he studied problems of optical manufacture and instrumental design under Ritchey. He went to Mt. Wilson in 1904, and was there responsible for parts of the design of the Snow telescope and the two Tower telescopes, and for the greater part of the design of the 100-inch telescope. In a very real sense he may be regarded as the father of the 200-inch telescope; always convinced of the need for telescopes larger than the 100-inch, he considered in some detail in 1926 (*P.A.S.P.*, **38**, 195, 1926) the various problems entailed in building a 25-foot telescope. Many of the solutions he then proposed have in fact been adopted in the final design of the 200-inch, and of course in that final design Pease, with others, played an important part.

No small part of his success as a designer arose from the fact that Pease was also a practical observer. Commencing at the Yerkes Observatory with the two-foot reflector, and continuing at Mt. Wilson with the 60- and 100-inch telescopes he made a series of photographic studies of nebulæ and star fields. A series of lunar photographs made by him with the 100-inch telescope in 1919 greatly stimulated his interest in this subject, and he was of great assistance to Dr. F. E. Wright of the Geophysical Laboratory of the Carnegie Institution in using these and other 100-inch photographs for the construction of a large-scale photographic map of the Moon.

The name of Pease will always be associated with that of Michelson in the first measurement of stellar diameters. In this investigation Pease was not only "the hands and eyes," but he was in no small measure responsible for the design of the 20-foot interferometer and its successor the 50-foot; with both instruments he carried out with consummate skill the highly difficult task of determining the mirror separation at which the fringes disappeared. Pease was also associated with Michelson and Pearson, both in the re-determination of the velocity of light and in a repetition of the Michelson-Morley experiment.

His sudden death on 1938 February 7 came as a great shock to his friends and associates. He was elected a Fellow of the Society on 1922 January 9.

JOHN WILLIAM ROBINSON PUNCH was born at Sedbergh, Yorkshire, on 1869 January 25. He practised as a solicitor in Middlesborough from 1890 to 1938, and was Clerk of the Peace for Middlesborough for twenty-seven years. For the last thirty years of his life he resided at Ellerstang, Castleton, and died there on 1938 July 4. Mr. Punch was a man of wide sympathies and many interests, so that astronomy, in which he became interested at the age of sixteen, was only one of his several avocations. He gave popular lectures on the subject to local societies and working men's clubs, and spent many happy hours with the 10-inch reflector in his observatory at Castleton. Other hobbies were geology and archæology, and his great love of country life and mountain scenery led him to be an

active member of the Cleveland branch of the Council for the Preservation of Rural England.

In 1894 he married Isabel Annie, daughter of Amos Hinton, of Middlesborough, who survives him with three daughters.

He was elected a Fellow of the Society on 1930 April 11.

ALEXANDER WILLIAM ROBERTS made his mark in two widely separated fields. He was a gifted amateur astronomer who by his observations and discoveries did much to enrich our knowledge of variable stars in the southern hemisphere, and was one of the pioneers in deducing the densities and ellipticities of eclipsing variables from their light curves. He was no less distinguished in the field of native education in South Africa, and he was one of the official representatives for native affairs in the Senate and a member of the permanent Native Affairs Commission.

Born in Sutherland, Scotland, in 1858, Roberts at the age of twenty-five went to Lovedale, South Africa, then under the principalship of the late Dr. Stewart, a friend and coadjutor of Livingstone. In Roberts's thirty-seven years of teaching there some 4000 native students passed through his hands, and yet in spite of what to anyone else would have appeared as a full-time career, he managed to make first-class contributions to astronomy. Commencing first with a pair of field glasses and a small theodolite, he investigated the periods and light curves of many short-period southern variable stars ; in this connection his name frequently appears in the early volumes of the British Astronomical Association, of which he was a foundation member. He was not content, however, merely with observing, but at a very early stage in his career he became interested in the interpretation of what he observed. It was no small achievement for an astronomer, living as Roberts did in almost complete scientific isolation, to carry so far the theory of eclipsing variable stars, and though that theory was not perfect and was later superseded by Russell's formulation, yet Roberts's early work was largely responsible for awakening the interests of astronomers in the dimensions of the stars.

He was a frequent contributor to the *Monthly Notices*, the *Astrophysical Journal* and the *Astronomical Journal* until about the year 1910, while reports from his small observatory appeared in the Annual Reports of Council until 1922. At that time the increasing pressure of public affairs and what he conceived to be his first duty—namely, native affairs—terminated that study of astronomy which was nearest his heart. He became a Fellow of the Society on 1894 March 9, and died at the age of eighty on 1938 January 27.

ARTHUR STANLEY WILLIAMS, who was born at Brighton in 1861, died at his home at Feock in Cornwall on 1938 November 21. He had been by profession a solicitor, but after his retirement resided at St. Mawes, Cornwall, before moving to Feock. He was always interested in scientific matters, and became one of the most outstanding non-professional

astronomers of modern times, ranking with such men as Dawes, Denning and Espin. He was elected a Fellow of the Society on 1884 May 9, and in 1923 he was awarded a Jackson-Gwilt medal for his work on the planets and on variable stars.

As a telescopic observer of the planets it is remarkable that he achieved so much with the simple and modest equipment he possessed. Practically the whole of his visual work was done with nothing larger than a $6\frac{1}{2}$-inch Calver reflector, which, though equatorially mounted, was without a clock-drive. In fact, it was not till within a year of his death that he obtained a larger instrument—a 9-inch reflector, and at once began to make with it observations of Jupiter. It was appropriate that his latest work should have been concerned with this planet, for at the beginning of his astronomical career he had shown himself a pioneer in its study. Individual spots and groups of spots on the planet's surface had been followed previously and in his own day by several observers, including Cassini, Schroeter, Beer and Mädler, Schmidt, Lohse, Terby, Barnard and Denning; moreover, the existence of the swift equatorial current had been discovered by the first-named observer in the latter part of the seventeenth century; but it was Williams who—collecting the results obtained, and adding to them his own researches—established the existence and positions of a number of definite currents in the planet's surface material, and showed that, despite temporary variations in their rate of drift, they were undoubtedly of a permanent nature. Among his earlier publications relating to Jupiter two stand out with special prominence—viz. his *Zenographical Fragments*, Part I., dedicated to the memory of Johan Hieronymus Schroeter, and containing the observations of objects in various latitudes during the apparition of 1886–87, and his classical paper "On the Drift of the Surface Material of Jupiter in Different Latitudes," published in *M.N.*, **56**, 143, 1896 January. These publications gave a great impetus to the systematic observation of Jupiter, and they have been the inspiration of the Jupiter Section of the British Astronomical Association to the present day. Incidentally it may be mentioned that the nomenclature of the Jovian belts and zones now generally adopted was also suggested by him (*M.N.*, **59**, 33, 1898).

Some reference may be made here to his sharp controversy with the late Professor G. W. Hough, Director of the Dearborn Observatory, as to the relative merits of the methods of determining longitudes of spots by simple eye-estimation of their central meridian transits and by micrometer measurements of their position. In this controversy it is generally agreed by observers that he was right in his championship of the method of transits. As a simple matter of fact it is not too much to say that almost the whole of our present-day knowledge of the surface currents of Jupiter has been derived from observations so obtained, and would not have been possible by any other method.

In addition to his assiduity in observation, Williams was particularly interested in the question of periodicity both as regards colour and surface drift. Here, however, he was on less stable ground, and there are those who feel that some of his conclusions are not quite so well assured. All

will, however, agree as to the value and importance of the inquiries he has made and the clues he has found. It will be for the future to establish, disprove or modify the conclusions he has drawn.

One of his most important papers was that entitled "Periodic Variations in the Colours of the two Equatorial Belts of Jupiter" (*M.N.*, 59, 7, 1899 April), which was followed by two later papers on the same subject. In this research he brought together the colour estimates of several earlier observers, going back—with inevitable gaps—to the times of Gruithuisen and of Schroeter, and combined with them observations by himself and contemporary observers. In this discussion it was usually necessary to convert verbal descriptions into numerical values, but these when plotted indicated a remarkable periodicity in about twelve years, the nature of the changes being that when the Northern belt is at a maximum of redness, the Southern belt is colourless or even slightly bluish, and *vice versa*, both belts showing a moderate degree of redness at intermediate periods. Observations subsequent to the publication of this paper can hardly be said to indicate the same clear-cut regularity in the oscillations, but the belts have usually been found to vary in an opposite manner, and on the whole there is considerable evidence of a general variation in the period of the planet's revolution. He further concluded that in the same interval of time the Equatorial Zone shows changes of colour ranging between a strong tawny hue and a white or colourless phase.

More recently Williams had done much to improve our knowledge of Jovian phenomena in the last century by a careful search through the scattered records of those days. Sometimes—as in the case of Boeddicker's work at Birr Castle between 1881 and 1886 (*B.A.A.J.*, 45, 199)—he was able to supplement scanty material provided by transit and micrometer observations by the measurement of drawings which helped him to establish suspected identifications and to draw trustworthy conclusions. Several papers dealing with possible periodicities in rotation periods were published in the *Monthly Notices*, but one of the most important of the results of this part of his work was the establishment of the fact that the retardation of the velocity of the S. Equatorial Current noted in recent times had been in progress since 1880.

A good deal of attention was also given by Williams to Saturn and Mars. On Saturn he observed spots in 1894, and Barnard's and other spots in 1903. On Mars he drew much detail, including the apparently linear features commonly called "canals", some of which he represented as double. But he was early convinced that the nature of their appearance was largely illusory, and he was in complete agreement with the conclusions derived by E. M. Antoniadi from observations with the 33-inch refractor at Meudon.

Williams's photometric work apparently began during a visit to Australia in the winter of 1885–86, when he collected data afterwards published in the form of *A Catalogue of the Magnitudes of* 1081 *Stars lying between* -30° *and the South Pole* (London, 1898). His detection at this time of the variability of the star now known as V Puppis in a period of 1·45 days

was the first of his many discoveries in the field of variable-star astronomy.

In his subsequent photometric researches he made use of a 4·4-inch portrait lens attached to his hand-driven equatorial for the purpose of *detecting* variability, and then used the 6½-inch mirror for visual observations to determine the nature of the light curves and the periods. The variables discovered as such by him included cepheids, eclipsing variables, long-period variables, and the well-known irregular variable RX Andromedæ. Two of his eclipsing stars—WY Tauri and VW Cygni—have periods of $0^d.346$ with a variation like that of β Lyræ and $18\frac{1}{2}$ days with a constant minimum of 8^h respectively. It is to be noted that Williams was the first British astronomer to make use of photography in the search for variable stars, though the method was employed at the observatories of Harvard and Moscow.

This short reference to his photometric researches must not close without mention of his work on Nova Persei 1901. This object, which was of magnitude 2·7 when discovered by Anderson on February $21^d\ 14^h\ 40^m$ G.M.T. (old reckoning), is not shown on a plate taken by Williams between $10^h\ 11^m$ and $11^h\ 27^m$ on February 20. Its rapid outburst and subsequent fluctuations interested him immensely, and he followed its changes assiduously till the end of 1911 when it was becoming too faint for his small aperture. Noting that stars of this kind, though abundantly observed when bright, are apt to be neglected in their fainter stages, he stressed the importance of long-continued observations, which, he claimed, might show by the nature (periodic or otherwise) of the fluctuations whether their cause lay within the star or in conditions—such as the existence of nebulosity of variable density—in the regions of space traversed.

Apart from his scientific work Williams's great interest was yachting. He was one of the foremost cruising men of his day, and most of his cruises were accomplished single-handed in his small 6-ton yacht *Ben-y-Gloa*. In 1914 he was awarded the Claymore Cup of the Royal Cruising Club, and in 1920 the Challenge Cup—the highest award that can be won in the world of cruising—for a single-handed cruise of 1254 miles from Falmouth to Vigo and back.

While at St. Mawes he lived in a barge named the *Queen* which he had turned into a comfortable cruiser. During the winter months this was beached, and it was there in 1930 that the writer of these notes had the pleasure of visiting him and seeing his observatory nearby a little way up on the shore. He was of a very retiring disposition and, apparently, but few people were aware of his ability and achievements. His lonely life was spent in communion with Nature and consecrated to his studies, and it was fitting that, in accordance with his desire, his body should have been taken by steamer to a point off Falmouth a few miles from land and, following a short religious service, committed to the sea he loved in the presence of just a couple of friends.

He is survived by a sister and some nephews and nieces.

T. E. R. PHILLIPS.

WILLIAM WALLACE CAMPBELL, one of the heroic scientific figures of his generation, was born on a farm in Ohio on 1862 April 11. After a strenuous life of high scientific and administrative devotion he died in San Francisco, California, on 1938 June 14.

He received the degree of B.S. in 1886 from the University of Michigan after a four-year course in civil engineering. A chance reading of Newcomb's *Popular Astronomy* suddenly turned his ambition toward a career in astronomy, and part of his senior year was devoted to a study of mathematical astronomy under the direction of Professor J. M. Schaeberle. After graduation he served for two years as professor of mathematics in the University of Colorado and then returned to Michigan as instructor in astronomy. Commenting on this change, which involved a reduction in both rank and salary, he once said that he gave himself some credit for knowing what he wanted to do. The summer of 1890 was spent as a volunteer assistant at the Lick Observatory, with the result that a few months later he was appointed astronomer in that institution in succession to James E. Keeler who had left to become director of the Allegheny Observatory. Keeler returned to Lick as director in 1898 but died two years later. Campbell was thereupon appointed director, a position which he held for thirty years, although after 1923 his supervision was of a very general nature, the actual administration of the observatory being in the hands of Dr. R. G. Aitken, Associate Director. When he accepted the presidency of the University of California in 1923, upon the urgent request of the Board of Regents, it was undoubtedly his intention, after a short term of service, to return to astronomical work, and later he deeply regretted that this plan could not be carried out. His tenure of office was not free from controversy and struggle, but he served the University ably and conscientiously and made a substantial contribution to its welfare and high academic standards. Weakened by illness, he drew too heavily upon his nervous energy and finally suffered a partial collapse during the graduating exercises at Berkeley in May 1930 and had to be assisted from the platform. He retired soon after, but later regained sufficient strength to serve as President of the National Academy of Sciences from 1931 to 1935. During a considerable part of the time he resided in Washington, D.C., in order to be in close touch with the affairs of the Academy.

He was president of the American Association for the Advancement of Science in 1915; of the American Astronomical Society, 1922–25; of the International Astronomical Union, 1922–25. He received medals and other honours from many important scientific organizations, while eight universities conferred upon him honorary doctors' degrees. He became an Associate of the Royal Astronomical Society in 1901 and was awarded its gold medal in 1906.

His marriage in 1892 to Elizabeth Thompson began an ideal companionship with a woman whose ability and devotion fully matched his own. All who know her admire her energy, judgment, and social grace. There are three sons: Wallace, Douglas, and Kenneth.

Campbell was an assiduous and versatile observer, to whom careless or shoddy work was anathema. He laboured with great energy and persistence,

and expected much of his associates. He strove habitually for quantity but never at the expense of quality. In the early part of his career his keen vision and ability to make accurate measurements of faint images were demonstrated in his visual observations of the spectra of nebulæ, and of other bright-line objects, particularly Wolf-Rayet stars.

His ruling passion for obtaining accurate data found its most important expression in the great radial velocity programme of the Lick Observatory, a programme remarkable for its enormous magnitude as well as for the sustained accuracy of the detailed results. In thirty-five years, 25,000 spectrograms of some 2800 stars were obtained with the 36-inch refractor at Mount Hamilton and the $36\frac{1}{2}$-inch reflector of the southern station in the outskirts of Santiago, Chile. Dozens of observers and measurers took part in carrying out the programme. At Mount Hamilton 31 observers each obtained 100 or more spectrograms, the leaders being J. H. Moore, 2422 ; W. H. Wright, 1956 ; W. W. Campbell, 1100. A large proportion of the spectrograms were with a three-prism instrument, dispersion about 11 A./mm., yielding for favourable spectra a probable error of 0·3 km./sec. for a single plate. The number of plates per star was seldom less than four, while many more were often obtained of stars exhibiting evidence of variable velocity. Long series of special stars, for example, Polaris, were obtained. The main objective, however, seems to have been the determination of the Sun's motion with respect to stars of visual apparent magnitude brighter than 5·5.

Since the stars were observed in the blue portion of the spectrum, the question may be raised why the limiting brightness was specified as a visual rather than a photographic apparent magnitude. The answer lies in the fact that for increasing colour index there is a partial compensation in the character of the spectrum. For the redder stars the absorption lines are more numerous ; hence the total energy in a given stretch of spectrum is concentrated on a smaller area of the emulsion. Moreover, to retain reasonable accuracy of measurement, the density of a plate of K- or M-type star may be less than for one of type A or B. Thus the effective "spectrographic" magnitude in the blue may in practice be represented as well by the visual as by the photographic magnitude.

Vogel and Scheiner at Potsdam in their pioneer measurements of the radial velocities of stars by photography had obtained for single spectrograms an average probable error of 2·6 km./sec. With the Mills spectrograph attached to the 36-inch refractor at Mount Hamilton, "probable errors were reduced at once from 2·6 km. to half a km. per second for the brighter stars containing good lines, and down to nearly a quarter of a km. for bright stars containing the best quality of lines. What was still more important, systematic errors appeared to be of minute or vanishing size. One photograph with this instrument gives greater accuracy, depending upon the character of spectrum, than could be obtained from ten to fifty spectrograms made with its predecessors." (*Stellar Motions*, p. 45.)

The further development of the stellar spectrograph to a point where negatives requiring long exposures yielded practically as reliable results as

those obtainable in a minute or two, was made in the first decade of the present century. In this accomplishment Campbell had the advantage of W. H. Wright's keen insight and engineering training. Later in carrying out the programme, in keeping it free from errors, and in the final discussion and publication of results, J. H. Moore took an increasingly important part.

Campbell early realized that his proposed statistical studies of stellar motions would be greatly strengthened if velocities were available for stars in all portions of the sky. In his own words (*Publications Lick Obs.*, vol. ix, p. 5), "Whether we are concerned with the motion of the solar system through space, or with the structure of the sidereal system, we certainly can not hope to base a satisfactory solution upon radial velocities of the stars confined to one-half or two-thirds of the sky. Let our radial-velocity determinations in the northern hemisphere be as complete and accurate as it is possible to make them : they can not attain their full strategic value until they are supplemented by equally extensive and accurate observations in the southern hemisphere." The only way to obtain the data for stars in large southern declinations was to establish an observatory in the southern hemisphere. Accordingly, with the financial assistance of D. O. Mills, and later his son Ogden Mills, a southern station equipped with a $36\frac{1}{2}$-inch reflector and suitable spectrographs was maintained near Santiago, Chile, from 1903 to 1929. Circumstances prevented Campbell from conducting the expedition in person as he originally planned, and in spite of his keen interest, he was never able even to visit the station. The work was ably conducted by the following astronomers who were successively in charge for terms of three to five years : W. H. Wright, H. D. Curtis, J. H. Moore, R. E. Wilson, C. M. Huffer, G. F. Paddock, F. J. Neubauer. The total number of spectrograms obtained was about 10,000.

The chief features of Campbell's general statistical discussion of his data are the determination of the Sun's motion "in space" and of the average random velocities of stars of various spectral types. For such discussions the accuracy required for the motions of individual stars is less than that sought after and attained in Campbell's observations. This is because the relatively large random motions of individual stars enter the equations in the same manner as accidental errors of measurement. Nor has anyone up to the present time devised a theory of stellar motions which yields small residuals for individual stars, although the hypothesis of galactic rotation, and, in a sense, the recognition of the general asymmetry of high stellar velocities, are important steps in that direction. From this point of view, therefore, it seems that it would have been better to observe more stars, especially fainter stars, with lower accuracy. There are two possible replies to this criticism. One is that the time may yet come when a perfected theory of stellar motions will utilize precise velocity data. Until this occurs we shall probably not know very much about stellar evolution. One of the least tractable problems of modern astrophysics is the explanation of the remarkable correlations between the motions of the stars and their physical properties. Campbell's discussion of the systematic progression of velocity with spectral type has the merit, not always appreciated, of displaying and

emphasizing this problem. The second possible reply is that the by-products of the programme, including the discovery of 339 spectroscopic binaries, may be judged to be as valuable as the statistical discussions. In fact Campbell himself wrote: "The unexpected by-products of the observations are scarcely less important than the foreseen results." These valuable by-products did, in many instances, depend upon precise and reliable measurements. Probably Campbell should have encouraged more branching out from the main programme and further exploitation of the subordinate investigations.

In a characteristically thorough investigation carried out between 1913 and 1918 the radial velocities of 125 bright-line nebulæ, many of them faint, were determined, and the high velocities of the planetaries demonstrated. About 15 persons shared in the actual observing. Laborious observations of the internal motions of 46 planetaries yielded positive results in 25 objects. In most, but not all instances, the observed motions were considered interpretable as axial rotations.

Campbell was in charge of seven Crocker Eclipse Expeditions from the Lick Observatory, beginning with the one to Jeur, India, in January 1898. These brought back a wealth of material on the corona (not yet fully utilized) and on the flash spectrum, of which Dr. Menzel's comprehensive discussion is well known. The "moving plate" method, providing a continuous record of the behaviour of spectral lines at the limb of the Sun at the time of second or third contact, has proved very important. The difficult problem of the Einstein displacement of stars seen near the Sun at eclipse was tackled on the Australian expedition of 1922. Dr. Trumpler's discussion of the photographs is thought to afford the strongest evidence we have as yet for the existence of the displacement.

Campbell's fondness for expeditions is further illustrated by his trip in 1909 to the summit of Mount Whitney, altitude 14,500 feet, to make a spectroscopic study of the atmosphere of Mars from a point where the interference by terrestrial absorption bands is as small as possible. His conclusion was that the amounts of water vapour and of molecular oxygen above the surface of the planet are extremely meagre.

Campbell's systematic pioneer investigations brought into prominence the problems of several groups of objects with peculiar spectra, and thus exposed to plain view attractive fields of research which to-day are receiving ever-increasing attention. Moreover, the influence on observational astronomy, especially in the United States, of his work on radial motions was incalculable. In his hands the spectroscope, a magic wand yielding astonishing insight into cosmic physics and chemistry, became a tool for obtaining precise quantitative data amenable to numerical calculation. The geometrical and dynamical problems thus brought under definite, detailed attack have given to modern astronomy an aspect with which Campbell's name should for ever be associated.

In spite of important administrative duties, in which he never shirked responsibility, Campbell stands out in the scientific world as an ambitious, energetic observer—a specialist, willing to devote his whole life's energy to

one type of research. He had an admiration amounting to a worshipful passion for observational results of the greatest possible precision, and a corresponding contempt for results of inferior accuracy. Inefficient or leisurely observing he could not abide. He regretted the loss of any portion, however small, of a clear night.

His personal influence on members of the staff of the Lick Observatory and on the numerous astronomical students of the University of California who received an important part of their training at Mount Hamilton was extraordinarily great.

Campbell was not one of those blown about by every idle wind of astronomical doctrine : no one ever called him a weather-vane. And the implication that he was not especially receptive to new tenors of thought is true. His method was to push ahead in his own established line of research rather than to experiment with trial balloons in the hope of reaching other levels. He has been criticized on this score, but, if criticism be limited to those who have accomplished as much as he, not many are entitled to be heard.

Scotch granite was a basic constituent of his moral character. He always firmly declined to deviate from his idea of what was right to please anybody, or for the sake of expediency. This gave him the reputation, more or less deserved, of being austere. He never, even in the slightest degree, camouflaged the facts or his own beliefs. All who knew Campbell respected his moral integrity and unswerving pursuit of truth. Many will join in the opinion of one of his colleagues at the University of California that "the greatest of his services, and they have all been great, is the example of character, rectitude of purpose and action, unfaltering devotion to family, to country and decent standards of civilization, which he set for us."

PAUL W. MERRILL.

ANDERS SEVERIN DONNER. By the death of Dr. Donner the Society loses one of its oldest Associates. As Director of the Helsingfors Observatory he volunteered to take a zone of the Astrographic Chart and Catalogue, and succeeded in carrying this through in his lifetime. This was no small achievement for a comparatively small observatory with limited resources.

Born at Helsingfors on 1854 Nov. 5, he was a student in the University of that city from 1871–76. He then went to Leipzig, Königsberg and Berlin, taking the Ph.D. degree in 1879. His early theoretical work was an application of Gyldén's theory to the perturbations of some minor planets. At the same time at the Observatory at Gotha he made meridian observations for the Helsingfors-Gotha section of the Astronomische-Gesellschaft Catalogue.

In 1881 he was appointed Assistant to Krueger in the Observatory at Helsingfors and became Director in 1883. He went on with Meridian work, including comparison stars for Sappho for Gill's parallax determination. The proposal by Admiral Mouchez for the formation of a chart of the heavens was heartily welcomed by Donner. He obtained the permission of his government to take a share in the work. A 13-inch photographic telescope

with a 10-inch guiding telescope was purchased from the brothers Henry, with an equatorial by Repsold. This was erected in Helsingfors in 1890 April, and the photography of the whole Zone—with plate centres in Zones 40° to 46° N. dec.—was completed in 1896. The measurement and determination of the plate constants was soon begun, and in 1903 the part from 9^h to 12^h was published. This volume contained 12,000 stars, the measured co-ordinates and magnitudes being given, as well as the right ascensions and declinations, obtained from plate constants determined from the catalogues of the Astronomische Gesellschaft. Intercomparison of overlapping plates were made to obtain better determinations of plate constants. A second volume of the stars between 6^h and 9^h was published in 1908. Successive volumes were published at intervals in association with Professor Rognar Furuhjelm, and the whole catalogue of nearly 300,000 stars was completed in 1937 by Furuhjelm and Järnefelt. Other researches were made on parallax and proper motions with Kapteyn, on plates of the North polar regions measured and discussed with Dr. Caroline Furness, and on a number of plates of Jupiter's satellites measured and discussed with Dr. Renz of Pulkowo.

Dr. Donner contributed to the discussions on the Astrographic Chart at the Paris Conferences and was one of the Joint Secretaries in 1896. There are but few members of those conferences living; those still alive remember Donner as a pleasant, learned and distinguished colleague. He was elected an Associate on 1907 June 14. He died on 1938 April 15.

F. W. DYSON.

GEORGE ELLERY HALE. A unique career ended on 1938 February 21 with the death of George Ellery Hale. More than any other single individual he was responsible for the rise of modern astrophysics. He early became convinced that observational astronomy and experimental physics have so much in common that results of far-reaching importance for astronomy must surely follow the introduction of physical methods in the study of the Sun and stars. His rare genius was devoted to translating this conviction into action.

The pioneering work of Huggins, Janssen, Lockyer and others had shown astronomy to be a subject filled with possibilities of an entirely new order. Their spectroscopes had glimpsed the fact that the Sun and stars are made of the same atoms long familiar in laboratories, but that the behaviour of these atoms was in some respects strikingly different from the behaviour of terrestrial atoms. Here was a powerful clue to the physical conditions of astronomical bodies. Clearly much might be learned, in spite of the great distances of these objects, if instruments and methods already well known to physicists could be adapted to the study of light from isolated points on the Sun and from faint and distant stars.

Hale saw this great opportunity and set himself the task of building the best possible instrument for the solution of each problem. His courage and enthusiasm were unlimited. Nothing could stop him. Others were inspired, some to join forces in the work itself, some outside the subject

to provide the necessary funds. From the beginning his success was amazing. He devised new solar equipment and with it made discoveries of far-reaching importance. Four times over he built the most powerful telescope in the world. In each case the telescope itself was regarded as necessary for the collection of light, but often less important than its accessories for analysing light and heat from cosmic sources.

Hale was born in Chicago on 1868 June 29. His father, William Ellery Hale, deserves great credit for recognising and encouraging his son's scientific ability. As a boy, Hale developed an intense interest in optical instruments. A Beck microscope was an early and highly prized possession. The views of minute organisms which it afforded led him to read Darwin's works and gave him a lasting interest in the problems of evolution which guided much of his later work on the Sun and stars. His interest in astronomy began when he was about fourteen. He made his first telescope himself, but soon afterward his father purchased for him a Clark refractor of four inches aperture with which he began his first real research by photographing sunspots and a partial eclipse of the Sun. It was not long before he had built a spectroscope and become fascinated by a comparison of flame and spark spectra with the spectrum of the Sun. As he says in his unpublished biographical notes, "Nothing could exceed my enthusiasm in observing the solar spectrum and in measuring the principal lines."

Between 1886 and 1890, Hale attended the Massachusetts Institute of Technology and gained there an engineering background which was of great value, since it enabled him to supervise every detail in the design and building of instruments at the observatories which he later established. It was while a student in Boston that he first conceived the idea of the spectroheliograph. He set up an experimental instrument at the Harvard Observatory in the winter of 1889–90 and tested it with a horizontal telescope. Although the equipment available at that time allowed only partial success, Hale was convinced that the instrument had great possibilities and must be developed at the earliest opportunity.

He discussed future plans for his work most carefully with his father. The spectroheliograph was uppermost in his mind, but it was clear that there would be difficulties in attempting to attach it to any of the existing telescopes. It was at this point that plans were made for the Kenwood Observatory. A 12-inch telescope was designed especially for the purpose, and was ordered by his father from Warner & Swasey. It was mounted near the spectroscopic laboratory which Hale had designed while at the Massachusetts Institute and in which he now had a Rowland concave grating.

The years from 1891 to 1895, largely spent in quiet research at the Kenwood Observatory, with ideal equipment for exploring the scientific results to be obtained with a new and brilliant invention, and free from the interruptions and responsibilities which inevitably came later, were among the happiest of Hale's life. Ellerman was his assistant during this period. No sooner had the first model of the spectroheliograph taken successful photographs of prominences in the light of hydrogen and calcium than

Hale designed a much better instrument with two travelling slits, one moving in the plane of the solar image and the other close to the photographic plate. A remarkably uniform rate of motion was attained through the use of a clepsydra. With this arrangement the bright calcium flocculi on the disc were photographed for the first time early in 1892, using the H and K lines of calcium which Hale himself had identified a short time before. Thus the way was opened to many observers for a wide variety of studies of solar phenomena.

Almost as soon as the spectroheliograph had been invented, Hale realized that it might be used to reveal the solar corona without an eclipse. He took the instrument to the clear air on Pike's Peak in 1893 and to Mount Ætna in 1894. When it became apparent that scattered light from the sky still obscured the corona, even in monochromatic light, Hale continued the attempt with a bolometer in the hope that this instrument might detect heat from the corona superimposed upon that from the sky. The method failed, but no one was more delighted than Hale when the news came, years later, that success had been achieved by Lyot, using an entirely different method. Hale's papers describing his early efforts to solve this problem are a fascinating example of his determination to use every possible physical principle in attacking an astronomical problem.

The work at Kenwood was interrupted by two visits to Europe in 1891 and 1893, during which Hale met many of the most active scientific workers both in England and on the Continent. One direct result of these visits was the establishment of the *Astrophysical Journal* to serve as a common meeting ground for astronomers and physicists throughout the world. One of Hale's strongest beliefs was that research progresses most rapidly and most surely when the interchange of ideas is facilitated between workers in distant laboratories and observatories.

The University of Chicago was founded by John D. Rockefeller in 1892. Hale was appointed Associate Professor of Astrophysics even before the new institution was formally opened. In President Harper he found sympathy and support for a plan to build for the new university an astrophysical observatory surpassing anything then in existence. Hale persuaded Mr. Yerkes to provide the lens and mounting for a 40-inch telescope. The equipment of the Kenwood Observatory was moved to Williams Bay, Wisconsin, where the new telescope was erected and formally dedicated in 1897. A group of investigators soon to become distinguished for their own contributions to the subject formed the staff of the Yerkes Observatory in its early years. This group included Adams, Barnard, Burnham, Ellerman, Frost and Wadsworth, with Hale as Director.

It was with the new Rumford spectroheliograph attached to the 40-inch refractor at Yerkes that Hale discovered the dark hydrogen flocculi, using the $H\beta$ line of hydrogen. The same instrument made possible a study of calcium flocculi at various levels corresponding to different points on the contours of the H and K lines. Hale also continued his study of the spectra of sunspots which he had begun at Kenwood. At this time he made his first experiments with a cœlostat to feed a solar telescope of long focus,

which resulted in the construction of the Snow telescope. In the field of stellar spectroscopy he did pioneer work on stars of Secchi's fourth type whose spectra had never before been photographed.

One might suppose that after the great struggle to bring the Yerkes Observatory into existence, and the remarkably successful work of its early years, Hale would have been more than satisfied to remain at Williams Bay. But he was one of those rare individuals who are never content with anything short of perfection. Excellent as was the equipment at Yerkes, it served in Hale's eyes merely to show what might be done with larger and more specialized equipment. He foresaw the advantages of solar spectrographs too long to be attached to the moving tube of a refractor and of solar images larger than that given by the 40-inch telescope. He also visualised the possibilities for stellar research of large reflecting telescopes, a type which had been out of fashion during the period when refractors were being pushed to their natural limit of about 40 inches aperture. Hale's father had acquired a 60-inch mirror blank soon after the building of the Yerkes Observatory, and Ritchey had been employed to figure this disc, which Hale hoped might be mounted as a powerful addition to the stellar equipment. The University of Chicago, however, was not able to provide the necessary funds.

The foundation of the Carnegie Institution of Washington gave Hale his great chance. Here was an organization devoted to the sole purpose of advancing knowledge. Hale took full advantage of the opportunity. He was made a member of a committee of the new Institution to study sites for a solar observatory. In 1903 he visited Southern California and joined Hussey in an investigation of observing conditions on Mount Wilson where he was much impressed by the clear and steady air. With Ellerman he erected in 1904 a six-inch lens of 60 feet focal length fed by a small cœlostat. Soon afterward the Carnegie Institution provided for bringing the Snow telescope to Mount Wilson. Hale was joined by Adams and Ritchey, and work started in earnest. Before the end of the year the Institution, largely through the effort of Dr. Charles D. Walcott, made a much larger appropriation to enable Hale to carry out his greater plan for Mount Wilson, which included not only a solar observatory but also the 60-inch reflecting telescope for a study of stars and nebulæ.

The years from 1904 to 1910 were full of activity and joy for Hale. Using the large solar image of the Snow telescope he and his colleagues photographed spectra of sunspots with high dispersion, and studied the strengthening, first noticed by Lockyer, of certain lines in the sunspot spectrum as compared with the spectrum of the disc. The laboratory, which Hale had always insisted must be close at hand for astrophysical investigations, and which he had built for the new observatory, amply justified itself by making possible the almost immediate discovery that those lines which are strengthened in sunspots are precisely the lines which are strongest in low-temperature sources, such as the furnace and the electric arc. Convincing evidence was thus produced for the belief that sunspots are cooler than other parts of the solar disc. A continuation of

the laboratory investigations, in the hands of King, has led to a classification of spectra of many elements which has greatly facilitated their interpretation on the basis of atomic structure.

Hale tried every possible device to improve the definition of the image of the Sun. He used electric fans to keep the mirrors cool in the Snow cœlostat and he spread white cheese-cloth on the surrounding ground and chaparral to prevent as far as possible warm air from rising to form disturbances in the optical path from the Sun to the first mirror. The 60-foot and the 150-foot towers were built, partly to raise the cœlostat further above the ground, partly to give a vertical enclosed path for the light on its way to the focal plane, and partly to give ideal conditions of thermal stability to spectrographs of very long focal length in pits under ground.

As soon as photographic plates reasonably sensitive to red light became available through the work of Wallace, Hale photographed the surface of the Sun in the radiation of $H\alpha$ with the new spectroheliograph of the Snow telescope. The hydrogen flocculi were much more pronounced than they had been on earlier photographs made with the blue hydrogen lines. Moreover, they showed a striking vortex structure, especially near sunspots, which immediately suggested to Hale the possible existence of magnetic fields produced by the rotation of charged particles. Even before this he had suspected that the doubling of some lines in spot spectra might be due to the Zeeman effect in a magnetic field. The 30-foot spectrograph of the new 60-foot tower, with a Fresnel rhomb and a Nicol prism, was used for an immediate test. The results were in exact accordance with the requirements of theory and established beyond doubt the magnetic properties of sunspots, including the opposite polarities in the two hemispheres and later the reversal of polarities at the end of each eleven-year period.

Throughout his career, Hale's principal aim was to make a detailed study of the Sun by every method available, not only for its own interest, but because it is the only star near enough to the earth to permit a critical examination of its surface. He was, however, equally eager to study the brighter stars with all the means he could command in the hope that a comparison of stars of different kinds, combined with first-hand knowledge of a single individual example, would help to elucidate the far-reaching problems of stellar evolution. This was his primary reason for urging the construction of the 60-inch telescope. Even before this instrument was finished he became convinced that a still larger aperture would be needed for the extension of important studies to include fainter and more distant objects. Mr. Hooker's timely offer of a 100-inch disc was therefore eagerly accepted, with full confidence that the mechanical problems of designing a suitable mounting could be met. The Carnegie Institution of Washington in due course undertook this project with results which are well known.

Hale's high dispersion solar spectra obtained with a Rowland grating at Kenwood and at Yerkes led his fertile imagination to foresee the tremendous importance of making every effort to obtain the spectra of stars on the same open scale, with spectrographs of such power that spectral lines lying close together would be clearly separated, and that the fainter lines in the spectrum

would be revealed. In collaboration with Adams, Hale obtained the first high-dispersion spectrum of a star, Arcturus, using the Snow telescope and a plane grating spectrograph with an exposure lasting five nights. The amazing detail recorded on this photograph showed that further efforts in this field would be amply justified with the 60-inch telescope. His strength did not permit Hale to do much observing at night, but the work was continued by Adams and by others, first with the 60-inch and later with the 100-inch telescope. Hale was greatly impressed with the advantages of the coudé type of mounting for a reflecting telescope, the design of which was first suggested by Ranyard and was improved by Wadsworth. It was largely due to Hale that provision was made, in the case of both telescopes, for bringing a stellar beam of light to a fixed focus where spectrographs of unlimited size, as well as thermocouples and radiometers, may be used under controlled laboratory conditions. Recent results obtained on high-dispersion spectra of the stars are in great part the realization of Hale's vision many years ago.

The strain of twenty years of tremendous mental and physical exertion, with hardly a moment free from the intense excitement of scientific work, had its effect in 1910. A series of nervous breakdowns prevented Hale, more and more, from taking an active part on Mount Wilson. This was the keenest disappointment of his life, but he met it with courage. He resigned the directorship of the Observatory in 1923 and built, largely at his own expense, a private solar observatory in Pasadena where he carried on his research up to the limits of his strength and where he continued to exert a profound effect on the development of the entire subject. It was here that he invented the spectrohelioscope and organized a chain of observing stations to keep an uninterrupted watch on solar phenomena. It was here, too, that he continued his long and painstaking effort to determine whether or not the Sun possesses a general magnetic field. This investigation, extending over nearly thirty years, in which he had the collaboration of many of the Mount Wilson staff, is a model of patience and of scientific caution in drawing conclusions. The methods employed included visual and photo-electric measures made on photographs and later on the spectrum itself. That the results, which strongly suggest the existence of a general magnetic field, still indicate the need for further work only shows how difficult the problem is.

The last great achievement of Hale's career was the project for the 200-inch telescope. Within a few weeks of the time when he first suggested the idea in 1928, the General Education Board provided funds sufficient for the whole undertaking. Once again had been demonstrated the extraordinary confidence that men felt in Hale's visions for the future.

> "Hand him the keys of the place on your knees
> 'Tis the dreamer whose dreams come true."

Into the plans for the new observatory Hale built all of the experience gained at Yerkes and Mount Wilson, including an astrophysical laboratory and a first-class machine-shop for the construction of auxiliary equipment.

The results of Hale's researches, which cover a wide variety of subjects, have been published in more than 400 papers and in several books of a less technical kind, including *The Depths of the Universe*, *The New Heavens*, *Signals from the Stars*, *Beyond the Milky Way* and *Ten Years' Work of a Mountain Observatory*.

Hale's direct contributions to astrophysical research were very great, but his contributions to the progress of science as a whole were equally impressive. His founding of the *Astrophysical Journal*, his creation of the International Union for Co-operation in Solar Research, his establishment of the National Research Council during the War and later of the International Research Council, from which the International Astronomical Union developed, are examples of his gift for seeing to the heart of those larger problems which are human as well as scientific, and for bringing together the best abilities from every source.

It was largely through his efforts that the California Institute of Technology has taken its present place in the scientific and educational field. He was also primarily responsible for the establishment of the Huntington Library as a research institution.

Scientific honours came to Hale from almost every country in the world, including in 1932 the award of the Copley Medal of the Royal Society. He was elected a Fellow of the Society on 1891 May 8, an Associate on 1899 November 10, and was awarded the Gold Medal in 1904. With characteristic modesty he always regarded these as tributes to be shared with those who worked with him.

Hale had an amazingly quick mind and a delightful sense of humour which made a talk with him on science, politics or art a stimulating experience. His sympathetic understanding of the points of view of others was unusual in a man of such intense activity. On his co-workers the influence of his personality is hard to define but was very real. He imparted to them a portion of his glowing enthusiasm and stirred their own powers to greater efforts. It was an unforgettable experience to work with him.

He and his wife, who was Miss Evelina Conklin, both did much for the good of Pasadena and were greatly loved there. Mrs. Hale survives him, with their son and daughter and eight grandchildren.

Hale has left to the world the most powerful equipment ever assembled for an exploration of the universe, brilliant scientific discoveries, and a group of workers touched by the fire of his spirit.

THEODORE DUNHAM, JR.

WILLIAM HENRY PICKERING was equally well known amongst all classes of astronomers, since he brought the technical qualifications, instrumental equipment and full-time employment of the professional to bear on many problems frequently attacked by less favourably equipped amateurs. Like his elder brother, the late Professor E. C. Pickering, he possessed a lifelong keenness and energy which enabled him to carry through a considerable amount of arduous work.

He was born at Boston, Mass., on 1858 February 15, and educated at the Massachusetts Institute of Technology, where he was appointed to the staff after graduating in 1879. In 1887 he joined the staff of the Harvard College Observatory, being appointed later to the position of assistant Professor which he held until his retirement, in 1924, to his private observatory at Mandeville in Jamaica. Most of his remaining time was spent here, where he died on 1938 January 21, leaving a widow, two children and several grandchildren.

One of his earliest publications (possibly the first) took the form of a communication to the *M.N.* (**39**, 137, 1878) on his observations of coronal polarisation during the Solar Eclipse of 1878, made whilst still a student. This interest in eclipse work was maintained, and he was either a member or leader of expeditions from Harvard to the eclipses of 1886, 1889, 1893 and 1900. He also did some important pioneer work on celestial photography, beginning (in collaboration with his brother) as early as 1882. The study of Comets and Meteors attracted him for a time, but he is perhaps best known for his work on the Moon and Planets.

In the course of this lunar work he produced the first photographic atlas of the Moon, consisting of 80 plates (16 districts being each shown at 5 different phases) taken with a 12-inch telescope of 135-feet focal length. His work (both photographic and visual) led to the detection of periodic changes in colour or brightness of small spots in certain craters, such as Plato, Linné and Eratosthenes, which he attributed to the growth and decay of vegetation or hoar-frost. Although some of his deductions have not been generally accepted he has been honoured by having a lunar crater named after him in recognition of his work. In planetary work his most notable achievement was the discovery in 1899 of Phœbe, the 9th satellite of Saturn, and the remarkable phenomenon (at that time) of its retrograde motion. He also predicted the position of an extra-Neptunian Planet by a semi-graphical method depending on perturbations of Neptune (supplemented by those of Uranus and Saturn) which gave results according with the orbit of Pluto in some respects even more closely than those of Lowell. In addition he was an indefatigible visual observer of the planets—especially Mars, upon the main surface features of which he agreed with Lowell.

Professor Pickering was a great traveller and mountaineer, and it is interesting to note that it was he who first (1889) suggested Mount Wilson as a favourable observatory site—actually having erected a small Harvard substation (later abandoned) very near the position of the present Observatory. He also founded, and was for some time in charge of, the Harvard stations at Arequipa and Mandeville, the latter of which became his private observatory when he retired.

He was elected an Associate of the Society on 1910 June 10, and received numerous other honours, medals and prizes from scientific societies in different parts of the world.

D. L. EDWARDS.

PROCEEDINGS OF OBSERVATORIES

The following reports of the proceedings of observatories during the past year have been received from the respective Directors, who are alone responsible for them.

Royal Observatory, Greenwich
(*Director, Dr. H. Spencer Jones, F.R.S., Astronomer Royal*)

Airy Transit-Circle.—The observation of stars in the zone 0° to +24° declination, begun in 1931, was completed on 1938 April 30 despite bad observing weather. All stars have been observed at least five times and the majority six or more.

This is the last programme in fundamental astronomy which it is proposed to undertake with this instrument. The Airy transit-circle has been in use for over 87 years, and more star transits have been obtained with it than with any other. It will be retained in place and may be used for differential work; however, a new object-glass will be needed and the circle must also be redivided.

Since 1938 May, observations have been confined to the Sun, Moon and major and minor planets, with accompanying clock and azimuth stars. These observations are being continued while investigational observations are in progress with the Reversible Transit-Circle.

Progress has been held up on the preparation of a star-catalogue based on the observations from 1931–1938, as the staff is fully occupied with the reductions of the observations with the new Reversible Transit-Circle and the determination of the division errors.

The total number of transits observed during the year was 5143, including 131 of the Sun and 93 of the Moon.

New Reversible Transit-Circle.—Observations during the year have been mainly confined to transits, and have been directed towards discovering and, where possible, eliminating various sources of error.

It was soon found that transits made with the motor drive were very accurate, and only five selected contacts were considered necessary for each transit; but these five contacts represent five truly independent bisections, since the procedure is as follows :—

An audible signal is given with every contact, and is used as a warning of the approach of a "selected" contact; after each "selected" contact the micrometer wire is deliberately thrown off the star and a fresh bisection is then made before the next one. The audible signal was originally introduced to allow the observer to rest between contacts on slow stars, but the above extension to all stars has proved worth while.

A start was made in the late autumn of 1937 for laying the foundations of a system of right ascensions. Stars for clock and azimuth error were selected

from those contained in the FK3 Fundamental Catalogue and supplement. The right ascensions of that catalogue were adopted for the initial stage of the work. Right ascensions of clock stars will be retained when the observations are spread over a minimum period of four hours.

The azimuth determinations will depend primarily on the consecutive above and below pole transits of bright circumpolar stars near the zenith. In addition, there is a secondary list of stars between 70° and 90° declination whose transits will be used above or below pole at night only. Comparison of the two methods will afford some check on possible diurnal variation of azimuth and on possible lateral refraction.

This programme entailed watches spread over a longer time-interval, and it soon became apparent that some nights gave a definite run in the clock error amounting, in extreme cases, to a few hundredths of a second of time over a period which might be as short as four hours. This was provisionally attributed to drifts in the collimation and level, and a series of observations was started in which the collimation and level are observed frequently during the day and evening. In this way smoothed curves can be obtained for both quantities.

After completion of the zone catalogue programme with the Airy transit-circle it became possible to employ more observers on the new instrument, and long series of observations were started in July. In good weather these start in the morning and run on into the following night; about 40 per cent. of the time is occupied with observations of collimation and level, and the remainder with stars. Cases of drift in clock error using smoothed collimations and level are very rare.

The determination of collimation is somewhat difficult under certain conditions, since the collimators are in separate houses outside the dome. The south and west walls and the roofs of these houses have now been fitted with louvred screens to keep off the direct rays of the Sun, and it is hoped that this will improve the definition.

A number of thermometers have been attached to different parts of the instrument, and some interesting correlations have already been obtained between their readings and the collimation and level. A definite dependence of the collimation on the difference of temperature between the dome and the tube of the telescope is apparent. The subject is, however, very complicated, and more data are still needed.

Detachable masonite screens have been fitted round the piers to shield them from direct sunlight and to reduce the effect of any rapid temperature changes.

The determination of the division errors of the fixed circle has been continued. The errors of the quarter degree divisions have been determined, and the work is in progress on the remaining 5′ divisions. A provisional estimate of the total range of these division errors is approximately three-quarters of a second of arc.

Cookson Floating Zenith Telescope.—During the past year 331 plates were taken for the determination of the variation of latitude, and 4 plates for the determination of scale. The results for the latitude variation from July

1936, when the new programme was started, until May 1938, have been discussed and will shortly be published. It is not possible satisfactorily to separate the latitude variation and the corrections to the star places from so short a period of observations, so that it has been necessary to base the latitude determination mainly on those star pairs also observed in the previous programme. Preliminary corrections to the other pairs can then be obtained.

Two points of interest have emerged. The measured mean zenith distance of a pair is affected by (*a*) the direction of the wind, the difference for north and south winds being about 0″·07 ; and (*b*) the temperature gradient (N. to S.) across the top of the roof. These two effects are independent, there being no correlation between temperature gradient and the direction of the wind.

The definitive discussion of the observations taken during the years 1911–1936 has been completed and will be published in a Greenwich volume.

28-inch Refractor.—During the year 233 observations of double stars were made, distributed in separation as follows :—

Separation ...	> 2″·0	2″·0 – 1″·0	1″·0 – 0″·5	< 0″·5
No. of Obs. ...	17	50	90	76

In addition, Dr. G. V. Simonow of Bosscha Sterrenwacht, Lembang, Java, who has been visiting the observatory on leave since September, has made 102 measurements of double stars, most of which were also of close separation.

The comparison image micrometer has been used for all of these observations and it continues to give satisfaction. The high proportion of measures of pairs with separation less than a second of arc is wholly due to its use. They could not have been secured with any confidence with the filar micrometer under the conditions of definition that prevail at Greenwich.

The dome shutter mechanism, which had worn out, has been replaced by an entirely different one designed in the observatory workshop. Later, the dome rails fractured, and had to be repaired in several places. In all, the telescope was out of action for over three months of the summer and early autumn, and the programme has been much hampered.

Very little progress has been made with the interferometer. The apparatus was fitted and tried out in February but the seeing conditions were unsuitable. It appears that the definition must be good in order to observe the points of minimum visibility of the interference fringes with certainty.

Further tests under good conditions are planned, but there is no doubt that only a limited number of pairs is suitable for observation with the interferometer.

Thompson Equatorial.—1386 plates were taken for the determination of stellar parallax during the year, and 1132 were measured ; 30 parallaxes were completed. The parallaxes of 33 stars were published in the *Monthly Notices* for November. 112 plates were taken through the glass for the determination of proper motions. The probable error of the annual proper motions so determined is ± 0″·0012.

Yapp 36-inch Reflector.—In continuation of the colour temperature work using the slitless spectrograph 188 comparisons of 77 stars with standard stars were secured. 20 plates were taken at the telescope to determine the quantity ϕ'_0 (see *M.N.*, **96**, 832, 1936). The observational programme was completed in September, and all the plates were measured by November. Detailed results for 250 stars will shortly be published in a Greenwich volume.

The slitless spectrograph was dismounted in November and the new slit spectrograph substituted.

The hyperbolic Cassegrain was tested by Mr. Hargreaves, and was found to show many small hollows and lumps, and one major deformation. It also had a very strongly turned edge. Mr. Hargreaves was therefore commissioned to refigure it; his method was to figure a concave hyperboloid to the required formula by the usual methods and then to check the convex against it by interference fringes. He reports that except for the extreme edge, which is not used, the figure is now correct. Star tests of the 36-inch Cassegrain combination with a knife-edge in the Cassegrain focus show appreciable spherical aberration and some other errors; they are believed to be due to the main mirror, but are probably not relatively important under the conditions of seeing usual at Greenwich; nevertheless, if there is one patch of the mirror that sends little light through the slit then there is also one patch of the collimator lens that is little used, which may cause systematic errors in wave-length. If the slit is always in a plane through the zenith, these errors will vary with the parallactic angle.

Spectra of a number of stars have been obtained under various conditions, partly to make necessary minor adjustments and partly to ascertain the most satisfactory use to which the instrument can be put. Normal exposure times are 6 minutes for a star of magnitude 2·0, with a slit width of ·03 mm., a spectrum width of ·3 mm., and 3 prisms. An indicator has been fitted to the mechanism that rocks the glass plate under the slit (for widening stellar spectra). It was found essential to stop the rocking when the comparison spectrum was being photographed, and in order that the comparison spectrum may not cover the star's spectrum the plate must be stopped in the mid-position. Changes have been made in the method of photographing the comparison spectrum, with a view to eliminating some suspected causes of systematic error in wave-length.

A microphotometer of the Oxford pattern has been ordered from Messrs. Casella. A number of optical bench tests were made to see whether the deflections with narrow slit could be increased, and it was found that an infra-red achromat placed after the second microscope did in fact produce appreciable improvement. It has accordingly been specified in the contract.

Astrographic Equatorial.—Observations of the planet Eros for the purpose of correcting the orbit were continued and 45 plates were obtained on 15 nights up to March 1. After this date observation was discontinued owing to the low altitude of the planet.

Observations of Eros 1930–31.—During the year the measures on the remaining plates taken with the Cape 24-inch refractor together with those

made on the Yale (26-inch refractor), Johannesburg (10-inch triplet) and Melbourne (astrographic) plates—in all 486 positions—have been completely reduced. The resulting positions have been compared with Dr. Witt's ephemeris. The Tabular Place has also been computed for the series of observations made at Algiers (123 positions—*J.O.*, vol. **15**, No. 9; vol. **17**, No. 6), Prague (44 positions—*Pub. Obs. Nat. Prague*, No. 9) and Poulkovo (20 positions—*Poulk. Obs. Circ.*, No. 6) and compared with the observed places.

The resulting residuals—tabular *minus* observed—for all the observations reduced at Greenwich together with those for the observations made at Algiers, Prague and Poulkovo, and also the results published and communicated for Uccle, Leipzig and Zo-Sé have been plotted on squared paper and a curve drawn through the points. The agreement shown between the results is highly satisfactory.

The tabular places for the series of visual observations made at Johannesburg with the $26\frac{1}{2}$-inch refractor (*U.O. Circ.*, No. 88) have been computed and compared with the observed positions deduced from the published observations, which gave the position of the planet with reference to a comparison star.

Photoheliograph.—The Sun was photographed on 299 days at Greenwich and on 326 days at the Cape. Up to November 30, nine days are not represented in these series, but a plate for each of the missing days is available at Kodaikanal. The 1937 series of plates, complete for the year except for one day (November 3), has now been measured. The areas of spots have been reduced and give for the mean daily area, corrected for foreshortening, the value of 2073 millionths of the Sun's visible hemisphere. The highest mean daily area hitherto recorded for any year in the Greenwich series (*i.e.* since 1875) was 1537 in the year 1917.

The estimated mean daily area for the year 1938 is 1900 millionths. It seems probable that the peak of the current eleven-year cycle has now passed. Sunspot numbers based on Wolf's method of counting have been supplied quarterly to Zürich for incorporation in the solar *Bulletin*. The occurrence of large sunspots of area not less than 500 millionths of the Sun's hemisphere has been reported to the Radio Research Station, Slough. In accordance with requests received, sunspots of area not less than 1000 millionths (or smaller spots showing unusual activity spectroscopically) were also reported to the Engineer-in-Chief, General Post Office, and to the Superintendent of the magnetic observatory, Eskdalemuir. Such spots appear to give the best statistical index at present available of the probable occurrence of terrestrial magnetic storms.

Spectrohelioscope.—Observations were made of the Sun's disc in $H\alpha$ on 212 days and include radial velocity measures, searches for bright chromospheric eruptions and photometric measures. On 29 days observations were limited to a few minutes owing to weather conditions. Special watches for eruptive phenomena were kept on the largest groups of sunspots. Occasional observations were made in $H\beta$ when active phenomena were seen in $H\alpha$. 337 measures of radial velocity were made during 1938; the bulk of these

measures relate to absorption markings associated with sunspots. The largest component of radial velocity observed was one of −265 km./sec. belonging to a dark flocculus near a sunspot on September 23. In the same region, when near the east limb on September 20, an eruptive prominence was observed with components of radial velocity from −75 to +160 km./sec.

During the year, 118 bright chromospheric eruptions were recorded; 18 of these eruptions were considered of sufficient importance to report during their progress to the Radio Research Station, Slough. Quarterly returns of all eruptions observed are sent to Meudon for inclusion in the solar *Bulletin* and also to Slough.

The photometric measures of maximum intensity (not total intensity) made with either the lamp photometer or the direct-wedge attachments to the spectrohelioscope comprise 26 measures of prominences, 82 of bright flocculi and 9 of dark flocculi. Although the spectrohelioscope was used on a greater number of days than usual, conditions at Greenwich were poor generally for solar photometric measures.

Nautical Almanac Office.—During the year the routine work of the Office has steadily increased, and it has not been possible to make much progress towards overtaking the arrears in the publication of the *Nautical Almanac*. Both the standard and abridged editions were published in April, one month earlier than in the previous year. It is anticipated that the editions for 1940 will show a more substantial gain; the *Abridged Nautical Almanac* for 1940 was sent for press early in December, while the few remaining pages of the *Nautical Almanac* were passed for printing early in January 1939.

No major changes of content or presentation have been made in the *Almanac*, though complete tables for moonrise and moonset in southern latitudes have been added to both standard and abridged editions.

The occultation programme, consisting of the prediction of occultations at 59 stations for all stars brighter than magnitude 7·5 and the calculation of reduction elements for all such stars for which occultations can be observed in good conditions, has been continued without modification. During the year, in the course of predictions for 1941, 2511 stars were examined on the occultation machine; of these 1270 were retained, yielding 7999 approximate times for subsequent computation. The main stage of the predictions for 1941 has now been completed, and reduction elements for all the stars retained are nearing completion.

Considerable progress has been made towards implementing the resolution of the International Astronomical Union at the 1935 meeting in Paris, by which the Nautical Almanac Office will be responsible for the publication of a separate volume containing the apparent places of all the 1535 fundamental stars in the recently published FK3 catalogue. The opportunity was taken of the meeting of the International Astronomical Union in Stockholm to complete the discussion on the many details involved, with the directors of the other Almanac offices, and since then a start has been made on the preparation of copy for the new volume. The first volume issued will be for the year 1941 and will appear about the middle of 1940.

The second volume of Planetary Co-ordinates for the equinox of 1950·0

is now in the press and will be issued shortly. Owing to the pressure of other work, it has not been possible to complete the investigation into different methods of computing the perturbations of comets and minor planets, of which it had been intended to give three illustrations, and the volume will not now be further delayed.

Complete copy for the 7-figure table of the four principal trigonometrical functions for every second of time was sent to the printer in July and the proof-reading is now nearing completion. Publication is expected early in 1939.

On the suggestion of Professors Appleton and Chapman, tracks of both the visual and corpuscular eclipses of 1940 October 1 have been computed, and printed in the *Monthly Notices* (*M.N.*, **98**, 664 and 727). For the corpuscular eclipse, a method was devised of using the occultation machine for the preliminary delimitation of the tracks and for the approximate times of beginning and end of the eclipse at selected places. The technique developed will enable similar computations to be carried out in future without the necessity for elaborate calculation.

For the total eclipse of 1940 October 1, a supplement to the *Nautical Almanac* for 1940 has been prepared, with the co-operation of Professor Carroll ; this supplement has now been reproduced and will shortly be made available to all who are likely to require it. It constitutes a departure from the normal practice of the Office, in that it contains not only the fundamental general data relating to the eclipse, but also those required in the setting-up and adjustment of instruments. It is hoped that it will help to save observers the trouble of making intricate computations in the field. For the present eclipse, it was considered advisable to issue this information in a separate cyclostyled form, but, if the information contained in the supplement proves generally useful, it will be incorporated in future in the *Nautical Almanac*.

The *Air Almanac* has been re-designed, to make it more convenient in use. Great simplification has been attained at the expense of doubling its size. The old form of the *Air Almanac* was issued for 1938, the ephemeral sheets appearing separately for the first two quarters and for the second half of the year ; the new form does not lend itself to anything but a quarterly issue, and no attempt will be made to combine consecutive quarters. The volume for the first quarter of 1939 was published during December.

The computation for the *Astronomical Navigation Tables* which the Office is preparing on behalf of the Air Ministry has progressed according to schedule during the year, copy for more than three volumes having been completed. The printing of the first of these volumes has been subject to delays unconnected with the Office, but it is now anticipated that it will appear very shortly, and that subsequent volumes will follow at intervals of about three months.

The staff of the Office has been increased by two, in view of the additional work undertaken, and two calculating machines, a Marchant, model M, and a Muldivo, model 1 B.T.R., have been added to the equipment.

Clocks and Time Service.—Observations of clock error with the small reversible transit were obtained on 112 nights during the year. Three

different striding levels were employed at different periods, and the scatter of the clock-error determinations obtained on different nights correlates so closely with the behaviour of the level as to suggest that, at least in the past, errors of level were the main factor involved. The present level, which has a new bubble by Messrs. Cooke, Troughton & Simms, is more stable and more rapid than any previous one, and the scatter is appreciably smaller than it had been before.

Transit observations and wireless time-signals have all been recorded on the chronograph against Shortt No. 3, but for the purpose of plotting a smooth curve through the points so as to determine the provisional and final clock errors the time determinations have been referred to the mean of as many clocks as possible. From January 1 to September 30 the mean clock consisted of the five Shortt pendulums at Greenwich together with Shortt No. 13 at the National Physical Laboratory. Two of the Greenwich clocks, Nos. 16 and 49, record mean solar time instead of sidereal time. With No. 49, which runs undisturbed, this involves no difference in principle ; but No. 16, which controls all the time-signal transmissions, is magnetically corrected several times a day. Before it can be used in the mean clock, these corrections have to be subtracted again, and comparison with the other clocks shows that when this has been done No. 16 is as good as any of its fellows. The daily comparison of Shortt No. 13 with the Greenwich clocks has been effected by means of the 10-hr. Rugby rhythmic signal, which is regularly received at Teddington and Greenwich. From May 17 onwards similar comparisons of Shortt No. 4, at Edinburgh, have been received daily, and from October 1 this clock has been incorporated in the mean. On December 28 Shortt No. 49 was found stopped, and had to be removed from the mean.

Comparisons of individual clocks with the mean show that in addition to sudden changes of rate they also have a tendency to wander from a steady rate and then to return ; thus a linear interpolation between two clock errors determined say a week apart may give results several hundredths of a second out. This effect is of course greatly reduced by using the mean of a number of clocks ; it is hoped that the crystal clock to be installed in Greenwich will enable it to be practically eliminated. The crystal clock is now nearly ready for test by the National Physical Laboratory, after considerable delay by the firm responsible for the oscillating circuits.

The time-signal service has been maintained unaltered except for technical improvements. The published corrections include an allowance for lag in the recording apparatus, which has been determined weekly by receiving the signals on the tape chronograph in the ordinary way and simultaneously recording them photographically with the cathode-ray oscillograph. The Post Office Talking Clock, which is controlled by the Greenwich hourly signal sent out from Shortt No. 16, has proved a great success, and the service has been extended to several other cities. The average number of calls is now about 400,000 per week.

An R.M.E. short-wave receiver has been installed, with the object of picking up the short-wave signals from Arlington. No comparison with American time-signals has been possible since the Annapolis long-wave

transmitter ceased operating in 1934. It is hoped also to compare the long-wave and short-wave signals from Continental stations.

1940 Eclipse.—A portable equatorial mounting has been designed in co-operation with Messrs. Sir Howard Grubb, Parsons & Co. It will be able to carry either the astrographic or a 13-inch reflector and spectrograph, and is to be constructed with funds supplied by the Royal Society and the Joint Permanent Eclipse Committee. With the astrographic it will be used for remeasuring the Einstein effect; it is designed to permit of accurate and very rapid switching from the eclipse field to a comparison field and back during the eclipse. With the reflector and spectrograph it is hoped to determine the apparent magnitude of the Sun at two wave-lengths, taking advantage of the good sky and fair altitude of the eclipse site, either before or after the eclipse. It is also planned to use the mounting for other purposes.

The 12-inch Sheepshanks lens of the Cambridge Observatory, a triplet with excellent colour-corrections up to the red, was borrowed from Cambridge, by the courtesy of Prof. Sir A. S. Eddington, O.M., and after some bench tests was mounted in a tube in the 30-inch reflector tube on the axis of the Thompson equatorial. It was hoped that the use of panchromatic plates with such a lens, instead of ordinary plates with the astrographic, would give stronger star images for the same strength of coronal light, in which case the lens might have been used for determining the Einstein effect. However, the general aberrations of the Sheepshanks proved more serious than those of the astrographic, and the project has had to be abandoned.

A 3-prism spectrograph with 6-foot collimator and camera is being constructed for the observation of line-contours near the limb and in the chromosphere. The prisms and lenses have been supplied by Messrs. Hilger and were specially computed to give a flat field over the wave-length range specified. The definition appears to be excellent. A repeating back camera has been designed and constructed in the observatory workshop, where all the other mechanical parts except the slit are also being made. The camera will make 15 exposures on a single 10×15 plate, shifting the plate quickly between exposures; the entire manual operation of plate-holder and shutter is accomplished by turning a single crank at a uniform speed. This spectrograph is to be fed by a cœlostat and concave mirror, and it is proposed to guide on the edge of the Moon's disc. The slit was made by Messrs. Casella; it has polished stainless-steel jaws inclined a few degrees for guiding.

A design for a slitless spectrograph, which will be used to determine, by direct comparison with the stars, the apparent magnitude of the Sun at two wave-lengths, has been tested in the laboratory. A modified Littrow mounting is used, astigmatism being deliberately introduced for the purpose of broadening the star spectra without entailing intermittency effects. On December 31 a rough working model of the spectrograph was mounted at the breech end of the Sheepshanks tube on the Thompson equatorial, and its performance will be tested under working conditions.

Printing.—The complete volume and separate parts of *Greenwich*

Observations for 1936 are about to be distributed, and progress is being made with the printing of the *Observations for 1937*.

Staff.—Mr. W. M. H. Greaves, Chief Assistant, was appointed Astronomer Royal for Scotland and Professor of Astronomy at Edinburgh University on April 1. He was succeeded on June 15 by Dr. H. R. Hulme, Fellow of Caius College, Cambridge, formerly Lecturer at Liverpool University.

Miscellaneous.—Dr. G. V. Simonow, Assistant Astronomer of the Bosscha Sterrenwacht at Lembang, Java, has been at the Royal Observatory since September 1. He has been engaged principally on the study of Double Stars.

Dr. A. Beer of Mill Hill Observatory spent from October 10 to November 11 studying parallax work at the Observatory.

Royal Observatory, Edinburgh

(*Director, Professor W. M. H. Greaves, Astronomer Royal for Scotland*)

The present Astronomer Royal for Scotland was appointed on 1938, April 1.

A programme has been commenced on stars of spectral types O and B. It is proposed to measure the total intensities of the Balmer and other lines in the spectra of these stars. The spectra are being photographed with the 36-inch reflector used in conjunction with the spectrograph in its two-prism form. The plates are being calibrated with a multiple slit calibration spectrograph, the relative slit apertures being determined photometrically by the half-aperture method.

A microphotometer of the Moll pattern, using a thermo-couple as the sensitive element, has been constructed in the observatory workshop, and was brought into use in December. The observatory is indebted to the Professor of Engineering in the University of Edinburgh for allowing the resources of the Engineering Laboratory to be utilised in the course of the construction of the instrument. The tools in the observatory workshop are of limited scope, and the help, on occasions, of the Engineering Laboratory was greatly appreciated.

The 10-inch camera in the West Dome has been devoted to the search for variables in Selected Areas Nos. 2–19. Areas 5 and 6 have been examined and the results prepared for publication. The examination of Area 7 is well advanced. One of the variables found in Area 6 appears to have the unusual period of 41·5 days. A volunteer observer, Mr. J. R. Liddell, has assisted both in taking the plates and in their examination with the blink comparator. The lens was dismantled, cleaned and re-adjusted during the year.

The Rugby signal at 10^h U.T. is received daily, and its time of reception, as recorded by the free pendulum clock Shortt No. 4, is forwarded to Greenwich. This enables this clock to be incorporated in the Greenwich "Mean Clock."

Fifteen occultations of stars by the moon were observed during the year by a volunteer worker, Mr. I. Storey.

At its meeting in Stockholm the International Astronomical Union decided to finance the publication of the measures of the Perth Astrographic plates for Zone $-40°$, 6^h to 24^h. The measurement of the Perth plates for Zones $-38°$, $-39°$ and $-40°$ was performed at Edinburgh during the years 1908 to 1915, but up to the present no publication has been possible apart from the measures for Zone $-40°$, 0^h to 6^h, which were published by the Perth Observatory in 1922. The copy for press for the remainder of this zone has been finally checked, and it is hoped that the printing will proceed during the forthcoming year.

The proofs of No. 1 of the new "Publications of the Royal Observatory, Edinburgh," have been read, and the number will appear shortly. It contains descriptions of the method used in the adjustment of the 10-inch triplet lens, and of the blink comparator used in the examination of the plates exposed with this lens on the Selected Areas.

The observatory is indebted to the Astronomical Society of Edinburgh for some valuable additions to the library.

Royal Observatory, Cape of Good Hope
(*Director, Dr. J. Jackson, F.R.S., H.M. Astronomer*)

Reversible Transit Circle.—The observations of the Boss and Backlund-Hough stars south of declination $+35°$ begun in 1936 were continued. During the year 9038 transits were observed. These include observations of the Sun on 184 days, Venus on 113 days and Mercury on 71 days. The major planets were observed on 10 to 14 nights, and the four largest of the minor planets were observed about twice a week when they crossed the meridian during the evening hours. Eros was observed six times.

An investigation of the pivot errors was carried on during the year; by means of the original optical method in March and December, and by means of a Krupp Mikrotast Gauge in November and December. The Mikrotast Gauge was found to give very reliable and consistent results, indicating non-circularity of the pivots. It was used with the instrument out of its bearings and also with the instrument in its bearings, the readings being a function of the errors of the pivots at two or three points. With the instrument resting on its bearings and the gauge on the top, the readings gave the vertical displacement of the centre of the pivot together with the radius of the pivot towards the zenith. With the gauge lying at an angle of $45°$ from the top a diameter of the pivot was measured. But the interpretation of the readings is influenced by the length of the bearing surfaces, which corresponds to about $5°$ of the circumference at each of the four points of contact. The readings proved, however, that the pivot errors obtained by the optical method are reliable. The observations show that the horizontal displacement due to pivot errors agrees closely but is somewhat larger than that determined previously, but that the vertical dis-

placement which was very small when the instrument was erected is now considerable and about half that of the horizontal displacement. Pivot errors are being adopted on the basis of this year's observations and will be applied to the observations of the present catalogue, the reduction of which was held up pending the new determination of these errors.

The catalogue of stars observed in the years 1925–32 is being compared with the General Catalogue, recently published. For the 3267 zodiacal stars the differences in R.A. give

$$\text{Cape} - \text{G.C.} = -0^{s}\cdot0077 + 0^{s}\cdot0108 \cos\alpha - 0^{s}\cdot0181 \sin\alpha + 0^{s}\cdot0078 \cos 2\alpha - 0^{s}\cdot0010 \sin 2\alpha,$$

agreeing closely with the well-established correction to the Boss system. The declinations give Cape – G.C. = $-0''\cdot25$. For the 8400 stars brighter than magnitude 8·0 south of declination $-30°$, the comparison is being made in zones 10° wide and has been completed to 17 hours of R.A. The most striking feature so far revealed is a jump from about $+^{s}\cdot02$ to $-^{s}\cdot02$ in Cape – G.C. between 11^{h} and 17^{h} as we pass from north to south of declination $-60°$. This may arise from erroneous proper motion, as the interval between the epoch of the G.C. and the mean epoch of observation is 25 to 30 years. For the zone $-40°$ to $-52°$ the determinations of proper motion made here for the C.A.Z. indicate that the larger differences for individual stars can be explained in this way. It should be noted that the stars observed at the Cape do not include the stars of the P.G.C., so that only the poorer stars of the G.C. are concerned in this comparison. For stars in the Zone $-40°$ to $-52°$ not contained in the G.C., proper motions have been taken from the C.A.Z., and of the 8400 stars the proper motions of only 522 remain to be determined. The differences between Cape and the G.C. are being entered for each star in the copy for press.

The reduction of observations of the Sun, Mercury and Venus made in the years 1932–36 has been completed and the results discussed. The constant correction to the Boss system of right ascensions was found to be $-0^{s}\cdot070\pm\cdot009$, $-0^{s}\cdot057\pm\cdot013$ and $-0^{s}\cdot052\pm\cdot015$. The observations of stars between the equator and $-30°$ made in these years have been discussed for latitude and for E – W differences. The completion of the catalogue will be proceeded with when the previous catalogue is completed. Both catalogues are for the equinox of 1925·0.

Eight-inch Transit Circle.—The observation of standard stars for the Zone $-52°$ to $-56°$ was practically completed in 1938, four nights observing in 1939 being sufficient to complete the work. 4193 observations, including those of azimuth and fundamental stars, were made.

Photographic Zone Observations with the Wide Angle Lens—(a) *Zone* $-30°$ to $-35°$.—The corrections depending on the position on the plate as determined from an analysis of the residuals from overlapping plates have been applied. The residuals in R.A. have been converted from arc to time as far as 20 hours.

(b) *Zone* $-35°$ to $-40°$.—The selection of 12,000 stars for measurement and the reduction of old catalogue places to 1950·0 has been

completed. The standard co-ordinates have been computed to $19\frac{1}{2}$ hours of R.A. and the plates measured to $14\frac{1}{2}$ hours. Fifty-five plates have been measured this year.

(c) *Zone* $-52°$ *to* $-56°$.—Simultaneously with the observation of reference stars with the 8-inch transit circle the photography was completed, 101 plates being taken in the course of the year. The plate centres have been determined for all the plates. The reduction to 1950·0 of stars in the La Plata Zone Catalogue (1925·0) for $-52°$ to $-57°$ is in hand and has been completed to 11^h of R.A.—about 3000 stars.

Cape Astrographic Zones, $-40°$ *to* $-52°$.—The catalogue giving the position, precession, secular variation, photographic magnitude, proper motion and spectral type of 20,554 stars fainter than magnitude 9·0 in the C.P.D. was completed. All the proof sheets have been corrected and returned to the printers. A discussion of some of the results was published in the *Monthly Notices* for May.

Victoria Telescope.—The instrument was in use for the determination of stellar parallax on 259 nights. The number of plates obtained was 3660, and in addition 213 plates were obtained for the determination of proper motion of the stars in the 5th and 6th published lists. 2118 plates were measured for parallax and 92 were rejected. 4606 remain for measurement. Previously the measurement of plates was started before the complete series had been obtained, but as a result of the accumulation of plates we now have several complete series awaiting measurement.

The parallaxes of 86 stars were published in the *Monthly Notices* for November, bringing the total to 922. The results for an additional 38 stars are now available. The parallaxes of eight stars exceed $0''·100$, of which two are new—faint stars of large proper motion in the Cape Astrographic Zone.

A new breach piece has been fitted to the 18-inch visual telescope so that it can be used to take photographs through a yellow filter.

Photometric Lenses.—The main programme for this instrument will be the determination of the photographic and photovisual magnitudes of all the stars whose positions have been accurately determined photographically by the wide angle lens camera.

Unfortunately, on account of the slowness of the lenses and the faintness of some of the stars to be measured, it is not practicable to employ the simple method of the direct comparison of each star with a standard magnitude sequence. Various indirect methods have been tried. That finally adopted is to photograph each region through a diffraction grating, whose reduction constant gives the scale while the zero point will be found from a number of the brighter stars whose magnitudes are determined by direct comparison with a standard sequence.

For convenience in the identification of the stars during measurement, the plates will be taken so that their centres correspond with those taken with the wide angle lens camera from which the positions of the stars were determined. There will be two independent determinations of magnitude for each star. Only the central $5°$ by $5°$ of the $15°$ by $15°$ field

covered by the photometric lenses will be used, and thus the distance corrections, etc., are likely to prove completely negligible.

The nine Harvard "E Regions" at $-45°$ declination have been chosen for the standard sequences, and an attempt will be made to make them as far as is possible into a mutually consistent system. Diffraction gratings with a reduction of about two magnitudes have been made for each of the two lenses.

During the earlier part of 1938 some twenty pairs of preliminary trial plates were taken and measured. The programme proper was commenced in the second half of the year. 61 pairs of plates, photographic and photovisual, of the Zone $-30°$ to $-35°$, have since been obtained, of which 31 pairs have already been measured with the Schilt photometer. In addition a number of grating plates of the "E Regions," and of intercomparison plates between the Zone and the "E Regions" and between the "E Regions" themselves, have been obtained and measured.

Occultations.—The 46 occultations observed in 1938 have been reduced and the results sent to the society for publication. The mean correction to the longitude of the Moon given in the *Nautical Almanac*, based on Brown's Tables, is now only $+1''\cdot99$.

Photoheliograph.—This has been a relatively cloudy year. 689 plates were taken on 326 days, including zero plates on 28 days and 6 plates taken during the partial eclipse of the Sun on May 29.

Galactic Clusters.—Dr. Stoy has continued to take photographs of galactic clusters as opportunity offered. 45 plates were taken with the 24-inch photographic lens, and 12 with the 18-inch visual lens of the Victoria telescope. In addition two plates each were taken with the astrographic telescope and the wide angle lens.

Eros.—Besides the observations made with the transit circle, 8 photographs were taken with the astrographic telescope and one with the wide angle lens.

The observations of Eros made at the opposition of 1930–31 with the astrographic telescope have been corrected to the definitive positions of the reference stars and the results forwarded to the Astronomer Royal for incorporation in the general discussion for the determination of the solar parallax and the mass of the Moon. The results depend on the measurement of 532 plates in right ascension and 376 in declination.

Armagh Observatory
(*Director, Dr. E. M. Lindsay*)

Star-counts of the Southern Milky Way, commenced at the Boyden Station of the Harvard Observatory, have been continued at Armagh, using Harvard material. An increased annual grant from the Government of Northern Ireland is now available. A Department of Astronomy has been inaugurated at Queen's University, Belfast, thus bringing into closer contact the observatory and the university.

Cambridge Observatory
(*Director, Sir A. S. Eddington, O.M., F.R.S.*)

Photo-electric observations for the purpose of testing the constancy of the light of stars similar in physical constitution to the Sun (dwarf G stars) have been continued. Much of the time has been spent on auxiliary work in connection with the determination of the atmospheric extinction factor. The following observations were obtained by Mr. Green (a set of comparisons on one night being counted as one observation) : extinction factor, 34 ; G stars, 24 ; other purposes, 24.

Dr. Woolley has obtained the following observations of double stars :—

	Northumberland			Thorrowgood			Total
Separation	> 2″	2″ – 1″	< 1″	> 2″	2″ – 1″	< 1″	
Pairs	9	25	20	9	11	2	76
Measures	30	84	54	12	17	4	201

In October Dr. Woolley and Mr. J. R. F. Jeffreys began laboratory experiments in preparation for a determination of the Sun's apparent magnitude to be carried out by Davidson and Woolley in South Africa in 1940. A photo-electric cell and valve amplifier are used for the photometry. The laboratory apparatus has been brought to a stage at which it is possible to measure the transmission, in sensibly monochromatic light, of a dark glass cutting down three magnitudes with an error less than $0^{m}.01$. The polarization of a spectrograph has been carefully determined in several wave-lengths ; and a preliminary determination of the coefficient of reflection from an unsilvered glass surface has been made.

The following research students have been working at the Observatory : M. Krook (Isaac Newton Student), J. R. F. Jeffreys (Isaac Newton Student), D. S. Evans. Dr. Krook has published papers on ionisation in stellar atmospheres and on a new soluble case of the equations of formation of an absorption line (*M.N.*, **98**, 204, 477, 1938). Mr. Evans (who left to take an appointment at Oxford University Observatory in July) has investigated the influence of Stark effect on line-contours, especially in connection with the centre-to-limb variations of the hydrogen lines (*M.N.*, **99**, 17, 1938).

The Director has been investigating the problem of how far the properties of a star of variable polytropic index are intermediate between those of polytropes corresponding to the two extreme indices (*M.N.*, **99**, 4, 1938). Mr. H. C. Corben has been working on relativistic quantum theory under his supervision.

Solar Physics Observatory, Cambridge University
(*Director, Professor F. J. M. Stratton*)

Staff.—There are no changes in staff to report. Dr. Redman has been working at the observatory, while supervising in England the design of some of the optical instruments for the Radcliffe observatory, Pretoria. Mr. W. S. Tai has continued to do research work at the observatory.

Buildings.—An inner lining of Sundeala Hardboard has been provided for the dome of the 3-foot reflector, with an air space separating it from the roof of the dome. The inner lining is coated with aluminium paint on the side nearer to the roof. A ventilator at the top of the dome carries away the warm air from between the roof and the lining. A large diurnal range of temperature in the dome has thus been eliminated.

Instruments.—In the spectroheliograph adjustable metal frames allowing motions in two co-ordinates have been provided for the dark slides. These enable a number of photographs of small regions of the Sun to be secured with short time-intervals for the study of the development of solar eruptions. For photometric work a tube sensitometer is now used with the spectroheliograph and a stepped wedge with the spectrohelioscope.

A microphotometer has been developed and attached to the McClean Littrow spectrograph for the study of the profiles of Fraunhofer lines without the use of the photographic plate. It consists of a photo-electric cell and a D.C. amplifier with electrometer triode and grid leak resistance of 10^{11} ohms. A movable slit in the focal plane of the camera is driven along the spectrum and the corresponding galvanometer deflection is measured on a revolving drum. Preliminary work on the *Ca*I line at 4227A shows that a slit length of 1 mm. with a slit width of 0·05 mm. (=0·03A) can be used satisfactorily.

Solar Work.—Photographs of the disc in K_{232} light were secured on 126 days, in *Hα* light on 114 days; photographs of the limb on 25 and 63 days respectively. These observations were made on 143 days, an unusually large number for the year. Visual observations with the spectrohelioscope were made on 123 days.

On 10 days serial exposures were made at short intervals on areas shown to be active by the spectrohelioscopic observations. The number of bright chromospheric observations observed was 44; of these 2 were of class III (important), 11 of class II (medium) and 31 of class I (weak). During the first nine months of the year 13 fade-outs of medium-wave signals were recorded by the adjoining Cavendish radio field station while the spectrohelioscope was in use. On 10 occasions accompanying eruptions were first seen within a minute or two before or after a recorded fade-out; on 3 occasions no eruption accompanied the fade-out, while on 3 other occasions class I (weak) eruptions, observed while radio signals were being measured, were accompanied by no fade-out.

In addition to observations in *Hα* and *K* direct solar photographs have been taken at effective wave-lengths 3700A and 3200A during the course of eruptions. In one case only so far has an increase in ultra-violet radiation been detected coming from an eruptive area.

Stellar Work.—During the year 301 spectrograms of 62 stars were obtained with the Newall 25-inch refractor on 162 nights. Spectra in the yellow-green region were obtained of 44 stars of types G5 to K5. Total intensities have been measured of the D lines in 33 stars, of *Hβ* and *Mg* 5183A in 21 stars. The D lines show no absolute magnitude effect, while *Mg* 5183A shows a negative effect, in partial agreement with Russell's predictions.

The D lines change by about 10 per cent. for 0·1 of a spectral type at K0.

Equivalent widths of nearly 200 lines of neutral and ionized elements have been measured in the spectrum of δ Cephei, and those free from blends are being investigated for relative changes during the cycle. For β Lyræ the profiles of certain emission bands and accompanying absorption lines have been studied, also the radial velocities of the respective features.

A study of the spectrum of α Canum Venaticorum has shown the presence of *Gd* and *Dy* lines varying in strength in phase with those of *Eu*. The relations between the changes in line-strength, the magnitude and the colour temperature of the star are being examined.

An atlas showing the daily changes of spectrum of Nova Herculis 1934, for the range λ 3600—*Hα*, for the first four months after discovery is more than half completed. The plates are being prepared from nearly 1000 spectrograms kindly lent by the directors of 24 observatories. The work has meant reducing to a common scale spectra obtained with over 40 different instruments.

Other Investigations.—A table of wave-lengths and identifications of iron polar lines, together with a list of term values of *Fe*II has been published (*Annals of the Solar Physics Observatory*, **5**, pt. 1).

Durham University Observatory
(*Observer, Frank Sargent*)

The usual programme of variable stars has been followed during the year and 591 observations recorded.

Certain observations of Jupiter and Saturn were also made.

University Observatory, Glasgow
(*Director, Professor W. M. Smart*)

During the past year the observatory at Dowanhill, which was built in 1836, was evacuated and a new observatory, designed mainly for instructional purposes, is nearing completion in University Gardens, adjoining the principal University departments. The main building includes a large room to house the library and to provide accommodation for lantern lectures, rooms for the Director and his Assistant (Mr. T. R. Tannahill, M.A., B.Sc.) and an instrument room. On the high ground behind, a building for a 7-inch equatorial telescope and a small transit-house are being erected.

The Director and Mr. Tannahill have been engaged during the year in investigations on stellar motions, including a detailed study of the recently published Cape Photographic Proper Motions. The Director has also begun an investigation on Moving Clusters, the first part of which—on the Taurus Cluster—has already been communicated to the Society.

Mr. Tannahill and Dr. R. A. Robb have each given two public lectures on the "Elder Foundation" in Astronomy at the Royal Technical College, Glasgow.

The papers published during the year include: "The Constants of the Star-Streams from the Photographic Proper Motions of 1775 Stars," by W. M. Smart and T. R. Tannahill (*M.N.*, **98**, 563); "A Method of Deriving the Constants of the Velocity Ellipsoid from the Observed Radial Speeds of the Stars," by W. M. Smart and S. C. Chandrasekhar (*M.N.*, **98**, 658); and "Determination of the Constants of the Velocity Ellipsoid from Radial Speeds," by W. M. Smart (*M.N.*, **99**, 61).

Imperial College Observatory, South Kensington
(*Director, Professor H. Dingle*)

Courses of instruction to students have, as usual, been the main feature of the astronomical work of the observatory. The laboratory research and solar observations mentioned in the last report have been continued, and considerable progress has been made. Preparations have been begun for an expedition to observe the total solar eclipse of 1940 October 1 in South Africa, at which Professor Dingle hopes to carry out the programme attempted at Montreal in 1932, when clouds made observations impossible. For the forthcoming expedition a new image rotator, containing three aluminised quartz mirrors, has been obtained from Messrs. Grubb, Parsons by the Joint Permanent Eclipse Committee. It has been tested and found to work satisfactorily.

The Director attended the meeting of the International Astronomical Union at Stockholm in August.

University of London Observatory, Mill Hill, and University College Observatory
(*Director, Mr. C. C. L. Gregory, M.A., Wilson Observer*)

(a) *The Radcliffe Telescope.*—The new observatory building for this instrument and a library adjacent were completed by the end of March, after some delay through infiltration of water at the base of the pier. The cost of the buildings was £2300. The re-erection of the telescope, rising floor and dome, and the necessary furnishing of the buildings and additional equipment cost £1000; this included the replacement of the original driving clock by a Grubb synchronous motor drive. The new buildings were opened by the Astronomer Royal on July 1.

(b) *Observations.*—Few observations were made during the first half of the year owing to the reconstruction of the 4-prism spectrograph at Cambridge. During the second half of the year the Radcliffe telescope was used on 22 nights and 19 plates were taken, mostly for testing and

adjusting the object-glass. A start has now been made on repeating some of the plates taken in 1910 with long exposures for the determination of the proper motions in moving clusters. The Wilson telescope was used on 20 nights and 21 spectra were secured, mostly of α Andromedæ and γ Cassiopeiæ. Through the kindness of the Astronomer Royal, and at the suggestion of Sir Frank Dyson, Chairman of the Observatory Committee of Management, the First Assistant, Dr. A Beer, spent a month at the Royal Observatory taking part in the parallax programme. Soon after his return, however, he was unfortunately laid up with pleurisy until the end of the year. It was not found possible, under the circumstances, to start the parallax programme which had been proposed.

(c) *Instruments.*—After some further alterations and readjustments of the spectrograph, on its return from Cambridge, this instrument proved satisfactory. A new sensitometer was made in the workshop, the work being mainly supervised by Dr. Beer. Several other pieces of apparatus were also constructed, including a rotating shutter and light filter for the parallax observations, and a new condenser and inductance for the spark comparison spectra, which are now quite free from air lines.

(d) *The Library.*—Many valuable gifts have been made to the library, including early volumes of the *Monthly Notices* and a number of books which were given by Mrs. L. N. G. Filon.

(e) *Research.*—Mr. C. M. Chao, research student, was awarded the M.Sc. degree in astronomy on submitting a thesis on "The Spectroscopic System α Andromedæ." The work was done mainly in conjunction with Dr. Beer, and it involved the measurement and discussion of 50 new spectrograms, most of which were obtained at Cambridge. In October, I. H. A. Rahman and P. C. Chaudhuri joined the observatory as research students. Observed Photographic Magnitudes of the Super Nova in N.G.C. 1003 were published in *M.N.*, **98**, 216.

(f) *Visitors.*—The number of visitors to the observatory during the year was 320.

(g) *University College Observatory.*—The work, which is mostly instructional, has proceeded as usual. Three students, reading for the B.Sc. (Special) Degree in Astronomy, have worked at the University Observatory on two evenings in the week, where a part of the practical examination will be taken.

University Observatory, Oxford
(*Director, Professor H. H. Plaskett*)

Staff.—Dr. T. L. Page resigned his appointment as Chief Assistant in Astronomy on September 1, to accept an appointment at the University of Chicago. Mr. D. S. Evans was appointed Research Assistant on October 1.

Equipment.—A new Cassegrain mirror, giving an aperture ratio of $f/62$, was obtained for the solar telescope from Grubb, Parsons in July. Hartmann tests in August showed that the zonal aberration with this mirror is negligible, and that the residual astigmatism of the telescope amounts to $0{\cdot}7\ \lambda$. This

astigmatism has now been definitely traced to the two large flats, and is probably due to a slight cylindrical deformation of their surfaces ; in this latter event the astigmatism is insensitive to the angle of inclination at which the mirrors are used. A description of the telescope and the tests appears in *M.N.*, **99**, 219, 1939.

The essential mechanical parts of the solar spectroscope were completed and installed during the first half of the year. These included the mechanical controls, a metal-lined tube for carrying the light beam, and the system of temperature regulation. The instrument was brought into use in September; a preliminary study revealed that the definition was much improved by diaphragming off the lower half of the prism train, and in this form the spectroscope was in continuous use with the solar telescope for the balance of the year. A further study will shortly be undertaken of the nature and origin of the aberrations.

Astrophysics.—The following investigations were completed during the year : (1) Identifications and equivalent widths for the solar Swan band lines were obtained by Miss Adam, and used to determine excitation temperatures at the centre and limb (*M.N.*, **98**, 544). (2) Intensities of atomic lines and continuous spectra in the electrodeless discharge were determined by Dr. Page, and were found to be in accord with the predictions from Kramers' Law. A preliminary account of the investigations appears in Nature, **141**, 1137; **142**, 416. (3) Dr. Zanstra discovered an apparently new form of instability in fluid motion, and in a paper communicated to the Society suggested that the motion of prominences in streams is a consequence of this instability.

The following investigations were initiated or continued during the year : (1) With the new solar spectroscope Miss Adam obtained spectra of a number of faint lines at the centre and limb of the Sun, in order to determine whether the strengthening of these lines is due to interlocking. (2) Seventeen unsuccessful trial solutions of the numerical integration of the equation of transfer for absorption lines were made by the director ; a method of deriving a fairly accurate preliminary variation of η with optical depth was ultimately found, and this should enable the solution to be completed by iterative methods. Pending the completion of this problem the reduction of the observations on the surface brightness of the Sun has been temporarily suspended. (3) Mr. Evans obtained spectra of $H\alpha$ at the centre and limb of the Sun with the new solar spectroscope in order to test Unsöld's suggestion that the Balmer lines behave as if formed by pure absorption ($\epsilon = 1$). The spectroscopic resolving power for this work is being determined from the known profiles of the narrow D lines of *Na* formed in a short absorption tube.

Astrographic Catalogue.—Apart from 5 plates still awaiting measurement in Zone $+33°$, Mr. H. Scott Barrett has completed the determination of plate constants and the preparation of the copy for press for both this zone and Zone $+32°$. Following a grant made by the International Astronomical Union at its meeting in Stockholm, it is hoped to proceed with the printing of the volume for Zone $+32°$ during 1939.

Norman Lockyer Observatory, Sidmouth
(Director, Mr. D. L. Edwards)

Successful observations were made with one or more instruments on 102 nights out of a possible 105 during the year. The 12-inch McClean telescope was used on the best nights for getting spectra of early-type stars for colour-temperature work, while on nights with poorer seeing or much moonlight routine negatives of A-type stars and other miscellaneous negatives were obtained. A series of plates was also taken, at the request of Professor Stratton, of α CVn with standard star comparisons to test for possible variations in colour-temperature. The total number of negatives obtained was 105. The "Grubb" electric control of this instrument, which had become very badly worn, has been replaced with a later model of the same type of control, which is now working satisfactorily. The 9-inch Kensington instrument was used mainly on Be-type stars, especially γ Cas, and on the near ultra-violet region of some bright B-type stars. A series of focus plates was also taken in the red region up to $H\alpha$. The total number of plates taken with this telescope and the associated instruments was 70. The Mond photographic equatorial was used chiefly on star clusters and the Andromeda Nebula, the latter being at the special request of Dr. Redman.

A valuable addition has been made to the laboratory equipment in the form of an "Oxford" microphotometer, half the cost of which was generously given by the late Sir Robert Mond. This instrument has been installed and adjusted, and is now being brought into general use. A refrigerator has also been installed for the storage of photographic plates.

Work on colour-temperatures of stars from objective-prism spectra is being continued, and the preliminary work of investigating the numerous practical, photographic, instrumental, theoretical and other details of the proposed method is now nearing completion. Work is also being continued on some of the brighter Be-type stars, especially the recent interesting changes in the spectrum of γ Cas. The preliminary investigation by Mr. E. G. Williams and the Director on classification and luminosities of B-type stars from objective-prism spectra has been completed and the results communicated to the Society. It is hoped that further applications of this method may be made in the future.

A new series of publications (*N.L.O. Bulletins*) has been commenced as a medium for the publication of less technical articles, observatory information and shorter scientific papers. The first number contains (amongst other things) a description, with photographs, of Finsler's Comet by Professor Blumbach, an investigation by Mr. D. R. Barber on the spectrum of this comet, and a description by the Director of the tube sensitometer designed at the observatory. Future numbers will appear at irregular intervals.

Stonyhurst College Observatory
(*Director, Rev. J. P. Rowland, S.J.*)

The staff of the Observatory remains unchanged, and the usual routine work has been maintained throughout the year.

Drawings of the Sun have been made on all days when observation was possible, and these have been supplemented, as in former years, by copies of drawings made at Zürich, kindly supplied by Professor Brunner, to whom have been supplied copies of the Stonyhurst drawings for a number of days on which no observation was obtained at Zürich. Counts of groups and nuclei have been sent quarterly to Professor Brunner for the preparation of *Sunspot Numbers* and *Solar Character Figures*.

Dominion Observatory, Ottawa, Canada
(*Dominion Astronomer, R. Meldrum Stewart*)

Meridian Work and Time Service.—During the year observations with the meridian circle were continued on the programme of Backlund-Hough stars and observations were obtained on 90 days. Instrumental constants were determined regularly. Computation of star places was kept up to date as closely as possible. Observations were made on 167 nights with the reversible transit for clock corrections. The primary sidereal clocks were compared twice daily and have maintained satisfactory rates. Wireless time-signals were received from Rugby, Bordeaux, Nauen, Washington, Monte Grande and Rio de Janeiro, and the times of reception sent monthly to the International Time Bureau. A new signal clock, designed by the Dominion Astronomer, was installed for controlling and distributing mean time-signals, and has proved quite efficient. Time-signals were distributed by telephone and telegraph, by continuous short-wave transmission, and daily, except Sundays and holidays, over station CBO, Canadian Broadcasting Corporation, and station VAA, Department of Transport. The clock systems maintained in the various government buildings in Ottawa and synchronized from the observatory have performed satisfactorily with few interruptions. As in previous years, clocks, chronometers, watches and other timing mechanisms were repaired and rated. Tables of sunrise and sunset, moonrise and moonset for various places were made out on request.

Solar Physics.—The year, like 1937, was abnormally cloudy and hazy. Fifty-six solar photographs were made, usually under conditions unsuitable for securing spectrograms of good quality. Revision of the early work on the solar rotation was continued. A comprehensive outline of sunspot influences was published, including the results of numerous investigations made in recent years at the observatory of various physical and organic fluctuations. Further measurements of tree-sections from British Columbia and Newfoundland were made. The relationship of the sunspot cycle to hail, hail-insurance and the value of the prairie wheat crop was investigated on request.

Fifteen-inch Equatorial.—Observational work, which was entirely with

the photo-electric photometer, was restricted by shortage of staff. Among the stars observed were ζ Geminorum, α Virginis, δ Cephei, and γ Aquilæ. The light curve of ζ Geminorum indicated a shift in phase from curves recorded here previously. Microphotometer tracings were completed for Nova Lacertæ. As usual the telescope was employed for the entertainment of visitors every clear Saturday evening. The quarterly pamphlet of popular descriptions of observatory work and celestial objects was continued for distribution to visitors and other interested parties.

Photographic Photometry.—Observing conditions were slightly better than in 1937, 110 plates being obtained. The following Cepheid fields were observed along with their comparison fields: Y Aurigæ, RR Leonis, RS Bootis, R Coronæ Borealis, RZ Cephei. Series of plates of the Pleiades and the Polar Sequence have been made for comparison purposes and as a check on the method of measurement of the plates. Measurements were continued on the following fields: SY Aurigæ, Y Aurigæ, RZ Cephei, RR Leonis, RS Bootis and the polar region.

Meteor Observations.—Meteor observing, during the δ Aquarid and the Perseid showers in July and August respectively, was carried on under unfavourable conditions but with considerable success in visual records. Work during the Leonid shower in November proved more successful, the night of November 15 being exceptional; excellent visual results were obtained and three meteors recorded photographically.

David Dunlap Observatory, University of Toronto
(*Director, Professor R. K. Young*)

Spectrographic Work.—Observational work has been continued on a programme for the determination of the radial velocities of about 500 stars in and near the Kapteyn areas. In the last report this programme was noted as nearing completion. Since then we have decided to extend the number of plates for many of the stars from 4 to 6. This has involved considerably more observation. The results are now being assembled for publication. Approximately 75 of these stars are variable in velocity. The following binaries have been under observation and preliminary orbits determined: TX Leonis, HD 1826, 22124, 25638, 25639, 34762, 96528, 142926, 183794, 206155. The following stars are under observation though periods have not as yet been determined: HD 9312, 63630, 162936, 164898, 172187, 219634.

In addition to the general programme work and observation of the binary stars above, Dr. F. S. Hogg commenced a photometric photographic programme of observation on nebulæ and clusters with narrow-range colour filters. Dr. Millman obtained additional plates for the study of chlorophyl absorption in the atmosphere of Mars. Dr. Heard has continued his spectroscopic observation of γ Cassiopeiæ. About 68 spectra have been secured by Dr. Heard of Be type stars.

Newtonian Focus.—In collaboration with Dr. F. S. Hogg, Dr. Helen Sawyer Hogg obtained 88 photographs of globular clusters. Period deter-

mination in N.G.C. 6402 and N.G.C. 6934 is progressing. A summary of data on variable stars in globular clusters is nearly ready for publication.

Meteor Observation.—As in other years, observational programmes, including photographic and visual work, were planned for the maxima of well-known meteor showers. Exceptionally poor weather conditions were consistently met with. Only broken observations were possible of the Delta Aquarids, Perseids and Geminids. 68 hours exposure (mostly through clouds) with the direct cameras and spectrographs at the Dunlap Observatory was without results. A few photographs were obtained at co-operating stations. 25 fireballs were reported to the observatory and somewhat over 1000 visual observations of meteors were made at the observatory and co-operating stations.

The monthly feature *Meteor News*, which this year included a summary of the known meteorites of the world, was published for the fifth year.

Instrumental.—During the year a self-registering microphotometer following the general principles of the instrument at the Dominion Astrophysical Observatory was constructed in the observatory workshop by the director and Mr. Gerald Longworth. This instrument has been tested and used and proven very satisfactory. A new rotating-shutter multiple meteor spectrograph was designed and is partially constructed. A new grating spectrograph for the 74-inch telescope is under construction.

Publications.—"The Bright Nova of 1860 in the Globular Cluster Messier 80 and its Relation to Supernovæ." Helen B. Sawyer. *D.D.O., Comm.* No. 1.

"The Spectrum of Gamma Cassiopeiæ." J. F. Heard. *D.D.O., Comm.* No. 2.

"An ancient Chinese Sun-dial." W. C. White and P. M. Millman. *D.D.O., Comm.* No. 3.

"The Light Curve of Two Variable Stars in the Globular Clusters N.G.C. 6218 and 6254." Helen B. Sawyer. *D.D.O. Pub.*, 1, No. 2.

"One Hundred and Thirty New Variable Stars in Five Globular Clusters." Helen B. Sawyer. *D.A.O. Pub.*, 7, No. 5.

Dominion Astrophysical Observatory, Victoria, B.C.
(Head Astronomer, Dr. W. E. Harper)

The observing weather was 13 per cent. above the average. On 216 nights with 1424 hours observing 1485 spectrograms were secured. The twenty-year average shows 203 nights, 1258 hours and 1342 plates. Up to the end of the year 28,040 spectra and 250 direct photographs had been secured. Measurement of the spectra has nearly kept pace with observation.

Some additions to the equipment have been made. To prevent fogging of the telescope mirrors during the winter months, as sometimes happens, a device has been constructed consisting of a Callendar recorder with two platinum thermometers, one in each arm of a Wheatstone bridge. When a rise in the outside temperature occurs, heat is automatically supplied to both mirrors to bring them nearer the outside temperature, and as soon as

the necessary rise has been achieved, the heat is automatically shut off. An aluminising apparatus capable of coating mirrors up to 24 inches in diameter was built locally and put in operation. With it the two 19-inch secondary mirrors of the 72-inch telescope were aluminised early in the year. Improvements to the photometer for use with the 72-inch telescope have been made during the year.

Mr. Harper has been investigating the absolute magnitudes and spectroscopic parallaxes of Class A stars. The 654 stars of this class in Schlesinger's 1936 Catalogue for which spectra were available at Victoria were used to correlate absolute magnitude with type, line sharpness and intensity. From the empirical curves thus set up these 654 stars were re-determined for parallax along with 576 other stars of Class A for which no previous determination had been made. Studies of solar motion from 1366 stars of Class A having known parallaxes and radial velocities were made. These were divided into three groups, the basis of division being perpendicular distance from the galactic plane. The results show a small decrease in solar velocity, 19·4 to 17·1 km./sec., with increasing distance from the galactic plane. From 142 spectrograms of the star Boss 3511 taken over an interval of more than 20 years there appears to be no change in the orbital elements, and mean values were derived.

Dr. J. A. Pearce has been engaged largely in the observation of eclipsing variables with a view to determining or revising their spectrographic orbits. His programme contains about 20 of these stars. Several other binaries are under re-examination, of which three may be mentioned. From his 1935 observations of the star 57 Cygni it was seen that the line of apsides was in rotation, but it was uncertain whether the period of such rotation was 525 years or one quite short. From forty excellent spectra secured this year it is very definite that in the three-year interval the change in ω has been approximately 30°. The star κ Cancri, whose orbit was determined thirty years ago at Yerkes, was stated to show a double-line spectrum. From fine-grained plates Dr. Pearce finds the lines sharp but none double, and no change has occurred in the orbital elements in the thirty-year interval. Two series of spectra of Algol, numbering 120 in all, were taken and measured this year, and it is proposed to continue these observations over the long period. During eclipse the spectrum of the Class A companion star has been repeatedly photographed.

Dr. C. S. Beals has continued his studies of interstellar matter. Using the aluminium-on-glass grating for the bright stars in Orion and Leo the complexity of the interstellar sodium lines was amply confirmed, strengthening the conclusion that discrete clouds of interstellar material are probably a common feature of interstellar space. Observations of the P Cygni stars have been continued, mainly in the yellow and red regions, making use of three prisms as well as the first and second-order gratings. Through the use of new panchromatic films of exceptional speed it has been possible to obtain spectrograms of 9th magnitude stars, whereas formerly the 7th was the limit. A number of stars with spectral characteristics similar to α Cygni have been shown to have P Cygni characteristics, and the observa-

tions suggest that α Cygni and P Cygni stars are physically similar objects with temperature probably the main distinguishing characteristic.

Dr. R. M. Petrie has continued his spectrophotometric studies of double-lined spectroscopic binaries with the view of obtaining the difference in magnitude between the components from the line profiles. The profiles of several lines in 20 binaries have thus been determined and the values of Δm will be published shortly. Approximately 700 spectrograms of 16 spectroscopic binaries with known orbits have been secured. In many of these the radial velocity curves have been completed ; in others considerable measurement remains to be done. The orbit of β Arietis was thus redetermined from 134 spectrograms made at Michigan, Yerkes and Victoria. Three new spectroscopic binaries, HD 23277, HD 100018 and HD 207650 have been closely observed and for the β Cephei star HD 199140 a total of 64 slit spectrograms and 20 slitless were obtained.

Using the new aluminium-on-glass gratings which permit observation in the red region of the spectrum, Dr. Andrew McKellar has secured spectra of late-type stars for a study of the molecular absorption bands. The observation of faint R- and N-type stars is also proceeding. The spectrographic orbit of HD 195986 has been completed, while sufficient observations have been secured for a determination of the orbits of HD 110533 and HD 207826. The examination of the isotope effect in high dispersion spectra of the red bands of Li_2 has been essentially completed. In confirmation of previous investigations of this nature, it gives results on the mass ratio of Li^7 to Li^6 in agreement with those found by other methods.

Mr. K. O. Wright has made progress in the spectrophotometric study of solar-type stars. Plates covering the region λ 4600 to λ 5600 were obtained with the three-prism spectrograph and for the region λ 5500 to λ 6700 with the first order grating. The measurement of equivalent widths of 200 lines in the region λλ 4000–4600 was completed and curves of growth constructed, but a detailed analysis of the material awaits the completion of the measurements in the other regions.

During the year Nos. 1 and 2 of vol. vii of the *Publications D.A.O.* were distributed. Nos. 3, 4 and 5 are almost through the press, while Nos. 6 and 7 are in press. About a score of technical papers were prepared for various scientific meetings during the year. The script for a half-hour Coast to Coast broadcast describing the work of the observatory was prepared for January 20, and reports indicate it was well received.

Helwan Observatory, Ministry of Public Works, Egypt
(*Director, Dr. M. R. Madwar*)

Time-Service.—The time-service was maintained as usual, the error of the standard Shortt clock No. 1 being determined from star transits. Rhythmic W/T signals were received daily from Bordeaux and Rugby during the morning, and the times of the first and last signals were determined by the aural method.

The standard clock ran satisfactorily throughout the year, the range in

the rate being $0^s.27$ per day and the range in the temperature of the clock room 16°·7 C.

The reversible transit circle was used regularly, and 23 transits were taken throughout the year.

Reynolds Reflector.—The reflector was used during 43 nights; 26 on nebulæ, 9 test plates and 6 miscellaneous objects. The Ross lens and a new guiding eyepiece, ordered from Grubb, Parsons & Co., have been duly fitted and are in working order.

Nizamiah Observatory, Hyderabad
(*Director, Mr. T. P. Bhaskaran, M.A.*)

The programme of work with the astrographic telescope remained the same as in previous years; 190 plates were taken during the year, nearly all of them being in the regions of the Hyderabad astrographic zones, with a view to the determination of proper motions by comparison with the plates of the original series obtained for the astrographic catalogue.

The blink comparator was in regular use for the comparison and 151 pairs of plates were dealt with during the year. Excluding cases of known proper motion, the number of faint stars found to have motions exceeding $0''.15$ per year was 114. There were two stars of the 12th mag. with annual motions greater than one second of arc.

An astronomical camera with a 4-inch lens was acquired and has been temporarily mounted on the tube of the astrographic telescope, 21 plates were taken for adjustment and other purposes.

Proofs of vol. xi (Zone $+37°$) of the Hyderabad *Astrographic Catalogue* have been compared and finally passed for press, and copies will be ready for distribution early in 1939. The MS. of vol. xxii is ready for press, and arrangements have been made to have the printing of this volume also completed by the end of 1939.

Systematic observations of long period variable stars have been continued with the Grubb refractor; 1436 estimates of visual brightness were made during the year. The working list comprises mostly stars with faint minima.

The number of occultations of stars by the Moon observed in 1938 was 45 (disappearances 38, reappearances 7). The occultations observed in 1937 have been reduced and the results published in the *Monthly Notices.*

Observations with transit instrument have been made as usual for the determination of the errors of the standard clock.

Kodaikanal Observatory
(*Director, Dr. A. L. Narayan*)

The usual programme of work of the observatory has been continued as in previous years. Photoheliograms were obtained on 328 days, calcium flocculi plates on 322 days, calcium prominence plates on 303 days and $H\alpha$ flocculi plates on 283 days. One plate of calcium flocculi for each day was sent to the Solar Physics Observatory, Cambridge, as in former years.

Under the auspices of the International Astronomical Union K prominence and *Hα* disc spectroheliograms were collected from other observatories whenever complete observations were not possible at Kodaikanal. The statistical data regarding calcium prominences and hydrogen absorption markings are published in half-yearly bulletins of this observatory.

Daily character figures of solar activity according to *Hα* bright flocculi and *Hα* dark markings have been communicated to the Observatoire Fédéral, Zürich, for inclusion in the Bulletin of Character Figures published by the International Astronomical Union. Daily character figures as derived from calcium flocculi from Kodaikanal photographs are communicated for publication by the Solar Physics Observatory, Cambridge.

Observations with the Hale spectrohelioscope were made on all days of favourable weather except Sundays and holidays, special attention being given to bright chromospheric eruptions. A list of these eruptions, together with the times when the Sun was under observation, was sent quarterly to the Meudon Observatory, Paris, for inclusion in the Bulletin of Character Figures. The displacements observed in the prominences and in *Hα* dark and bright markings are summarised in the half-yearly bulletins of this observatory.

In continuation of observations and measurements of intensity profiles previously reported, the Director and Mr. C. K. Ananthasubrahmaniam have been engaged on a photometric study of the changes of Magnesium *b* group and other strong Fraunhofer lines from the centre of the Sun's disc to the polar and equatorial limb. The 3rd order spectrum of a 20-foot grating spectrograph was used for the purpose.

Dr. A. K. Das and Mr. B. G. Narayan have been making a statistical study of prominence areas to determine the possible influence of the earth on solar phenomena.

A line-shifter has been designed and mounted on the *Hα* spectroheliograph so as to record variations in form and details of prominences on the disc and the limb of the Sun due to Doppler effect.

The 6-inch cœlostat used with the 13-foot prism spectrograph constructed for line contour work was found not to have a sufficient light grasp. From the parts received from the Takthasingji Observatory, Poona, a 12-inch siderostat has been built up and mounted. For want of a 12-inch flat it is at present fitted with a 7-inch mirror. A monochromator for use with the spectrograph has also been constructed and mounted and a few experimental plates have been taken.

Laboratory Work.—Mr. M. Salaruddin and the Director photographed and measured the spark spectrum of Bromine from 2200 to 6500 A. A new multiplet has been identified and ^5D terms located. Precise measures of intensity have been made by photographic photometry, for the lines of the above multiplet under varying degrees of excitation.

Mr. Salaruddin and Dr. A. K. Das have measured the intensity of cosmic radiation at Agra and Kodaikanal and studied the diurnal variation of intensity with sidereal and mean times.

Union Observatory, Johannesburg
(Union Astronomer, Dr. H. E. Wood)

26½-*Inch Visual Refractor.*—2625 visual micrometrical measures of double stars were made during the year; the conditions for observing were very unfavourable during the winter months.

Occultations of Stars by the Moon.—The regular programme of observations of occultations of stars by the Moon was continued unchanged; 86 occultations were observed during the year.

The results of the year's observations are given below; the second column indicates the time by which the Moon has arrived too early at any longitude, and the third column the amount by which the Moon is ahead of its tabular longitude:

		s	″
	1938·09	4·4	2·5
	·32	6·0	3·3
	·58	4·5	2·5
	·82	3·5	2·0
Mean for year	1938·45	4·9	2·8

These results are, as in former reports, deduced from disappearances at the dark limb only. In obtaining the means, each occultation is given a weight equivalent to $\cos(\chi - \rho)$, and no occultation is included for which the value of $\cos(\chi - \rho)$ is less than 0·5.

Franklin-Adams Star Camera.—During the year 791 plates were taken with this instrument. The distribution of the plates was as follows:—

Variable Star Regions	488 plates.
Minor Planet Regions	261 ,,
Comet Regions	42 ,,

Comet 1927 vi Gale was searched for during the early part of the year. After its recovery at Harvard on May 1, observations were made here from June 4 to July 29. Comet 1925 ii Schwassmann-Wachmann was searched for in March but not found.

16 new minor planets were discovered during the year and elliptic orbits were computed for 5 minor planets. One of the new minor planets, 1938 KB, was identified as 855 Newcombia, which had not been observed since 1916.

274 approximate positions and 41 accurately measured positions of minor planets were forwarded to the Astronomisches Rechen-Institut.

Union Observatory Circulars.—Circulars Nos. 98, 99 and 100 have been published and distributed during the year.

Miscellaneous.—The twin 16-inch photographic refractor, made by Sir Howard Grubb, Parsons & Co. for the Leiden Rockefeller Foundation, was sent out from England and erected in October. Dr. A. de Sitter of the Leiden Observatory has been at the Union Observatory throughout the year.

The Union Astronomer attended the meetings of the International Astronomical Union at Stockholm and the meeting of the British Association at Cambridge.

The number of visitors to the observatory during the year was 1492.

Radcliffe Observatory, Pretoria
(*Director, Dr. H. Knox-Shaw, Radcliffe Observer*)

Work on the erection of the 74-inch reflector and its turret has proceeded steadily, if somewhat slowly. Early in April the steelwork of the turret arrived on the site, followed a few weeks later by the mechanical parts of the telescope. The erection was begun at once and was completed six months later. It would not have taken so long had a derrick capable of lifting the heavier parts of the telescope been available. As it was, these had to be dragged in through the doorway of the turret on greased rails and then hoisted up on to the observing floor through the lift shaft, which had to be enlarged for the purpose. Finally they were lifted into position by means of tackle suspended from a 60-foot steel mast resting on the observing floor. This was a lengthy and troublesome process, and it was a great relief when it was safely accomplished. By the end of the year all work on the turret was finished except for a few electrical connections.

The erection of the telescope is thus complete apart from the mirrors. The five secondary mirrors have been figured. The pyrex disc for the large mirror has at last been successfully cast by the Corning Glass Co. It arrived at the works of Sir Howard Grubb, Parsons & Co. early in October and appears to be a very good one. Satisfactory progress had been made with the rough grinding at the end of the year. It is hoped that the figuring may be completed by about the middle of 1939, and that the mirror will then be sent to Pasadena for aluminizing, Dr. W. S. Adams having kindly offered to have this done there, as no plant for such a large mirror is available in England.

What promises to be an extremely convenient projection machine for the measurement of spectrograms has been delivered, and a microphotometer almost completed, by C. F. Casella & Co. The two-prism Cassegrain spectrograph, which is being made by that firm and by Adam Hilger Ltd., should be ready before the middle of 1939. Dr. Redman has remained in England to superintend the construction of these and other subsidiary instruments. He has also found time to finish his work on the photometry of elliptical nebulæ (*M.N.*, **98**, 613), and to take some sunspot spectra. A paper by Mr. Williams, in collaboration with Mr. D. L. Edwards, was published during the year (*M.N.*, **98**, 467). He has also completed a paper on Nova Herculis, and made some observations on southern variable stars with the $3\frac{1}{4}$-inch Marlborough telescope.

Adelaide Observatory
(*Director, Mr. G. F. Dodwell, B.A., Government Astronomer*)

The routine work of the observatory (time service, seismology, educational work, etc.) has been continued as in previous years.

Latitude Variation.—1191 pairs of latitude stars were observed on 137 nights by Messrs. A. E. Markey and R. V. Burton. The results were sent to Professor L. Carnera at Naples, Director of the Central Bureau of the International Latitude Commission.

Obliquity of the Ecliptic.—A study of the ancient observations of the obliquity of the ecliptic has been continued, with special reference to the ancient Chinese observations.

Educational.—Lectures at the Adelaide University on Astronomy for Surveyors have been continued during the year.

Commonwealth Solar Observatory, Canberra, Australia
(*Officer-in-Charge, Mr. W. B. Rimmer*)

Sun Telescope.—The determination of the water-vapour content of the atmosphere in the path of the Sun's rays, as outlined in last year's report, has been continued. The calibration of this method by measurements for a horizontal air-path of 1680 metres, in which the amount of water-vapour was derived, has been completed. The observations cover both winter and summer conditions. The calibration constant is found to be slightly larger than that obtained with the infra-red spectrograph mentioned in previous reports. From simultaneous psychrometric measurements of the water-vapour pressure at the Earth's surface, the constant of Hann's equation has been derived: it is found to vary with the season of the year.

A photometric study of the Fraunhofer spectrum has been made in the region 3924–4300 A. The tables in the course of publication contain observations of 1400 measured central intensities and equivalent breadths, 400 corrected central intensities, wing intensities of several broad lines, and similar information published by other workers.

The contours of the *Na* D-lines have been determined for both the centre and limb of the Sun. The central intensity corrections were obtained by comparison with strong neighbouring water-vapour lines obtained at low altitudes of the Sun.

A study of the changes in structure and intensity of violet Fraunhofer lines near the Sun's limb is in progress. When the spectrum of the equatorial limb was compared with that of the polar limb for 16 lines near 4200 A no measurable intensity differences were found.

The study of eruption spectra has been continued when possible. The occurrence of hydrogen "bombs" is being systematically recorded on days of good visibility.

Farnham Telescope.—The direct photography of the solar disc has been continued on all possible days. The occultations of 17 stars by the Moon have been observed and reduced.

Solar Activity.—Routine daily observations of the solar disc have been continued with the Hale spectrohelioscope as in previous years. A brilliant eruption was observed on 1937 January 24, which appears to have been connected with the aurora of 1937 January 25–26. The relations between eruptions and related sunspot groups have been examined, using the results of solar eruption observations published in the *Zürich Bulletins for Character Figures of Solar Phenomena.* The co-ordination of observations of solar activity and ionospheric phenomena has been continued. Routine observations of the heights and densities of the main reflecting regions have been continued with new and improved automatic equipment. Three distinct types of disturbances in the ionosphere are now recognised. Two of these are of solar origin due, respectively, to increased ultra-violet radiation, and to the arrival of particles: the third is of special interest in that it is associated with definite meteorological conditions. An account of this work will be published shortly.

Publications.—Publications include "Velocity of a Dark Hydrogen Marking," *Observatory*, **61**, 136, 1938; "Recent Solar Eruptions, Auroras, and Magnetic Storms," *Nature*, **141**, 746, 1938; "Eruptive Prominences and Ionospheric Disturbances," *Ap. J.*, **88**, 204, 1938. The following papers are in course of publication, "Fraunhofer Intensity Table 3924–4300 A," and "The Relations between Eruptions and Sunspots."

General.—The programme of work, as outlined in the reports of previous years, has been continued. Continuous records of the intensity of Cosmic Radiation have been made since 1935 July 1.

Melbourne Observatory

(*Director, J. M. Baldwin, M.A., D.Sc., F.Inst.P., Government Astronomer*)

The observation of stars of the Provisional General List of Fundamental Stars has been continued during the year, the number of observations obtained—1774 in R.A. and 1006 in Dec.—being considerably less than usual, as the observational programme is now nearing completion. In addition to reduction of these observations, time has been devoted to further revision of Catalogue Me 5.

With the 8-inch equatorial 1621 observations of southern long-period variable stars have been made. The results have been forwarded to Harvard College Observatory each month, for publication with those of other members of the American Association of Variable Star Observers in the *Harvard Annals.* Observations of occultations listed for Melbourne in the *Nautical Almanac* have been made whenever possible. The reduction of these observations will be put in hand very shortly and the results will be forwarded to the Nautical Almanac Office.

A good deal of time has been devoted to the revision of Volumes 4 and 5 (Zones $-71°$ to $-74°$) of the *Astrographic Catalogue*, and the computation of final plate constants has now proceeded up to the middle of Zone $-79°$. Unfortunately there seems no immediate prospect of the publication of these two volumes.

Riverview College Observatory, Riverview, N.S.W.
(Director, Rev. D. O'Connell, S.J.)

Father W. O'Leary, S.J., retired from the Directorship at the beginning of the year, but will continue to work at the observatory.

About 900 plates were taken during the year in connection with the variable star programme. Experimental work is being done by Fr. O'Leary on two new types of comparators.

Publications.—Riverview Publication No. 4 (Photographic Light Curves of Variable Stars; Observations of Comet Peltier) was distributed during the year.

Sydney Observatory
(Director, Mr. James Nangle, O.B.E., Government Astronomer)

Towards the end of 1937 volumes 15 and 16 of the Sydney Section of the *Astrographic Catalogue* were printed. Volumes 13 and 14 are at present in the hands of the printer. During the year the work has proceeded at a somewhat faster rate. Two assistants, Misses M. B. Mills and B. Macara, have been appointed for plate-measuring and the preparation of manuscript for printing. Four further volumes are now complete and work on twelve more is in an advanced stage. Observations of reference stars have been continued with the 6-inch transit-circle.

The occultations predicted in the *Nautical Almanac* have been observed when possible.

The civil work of the observatory has been continued as usual. This consists chiefly in the supply of astronomical memoranda, and astronomical information for legal purposes, and the time service.

The educational work of the Observatory has continued during the year and lectures on Astronomy have been delivered regularly.

1544 persons visited the observatory during the year and were shown the uses of various instruments. Time has been devoted to demonstrations to students of the Teachers' College and University.

In February Mr. W. C. Graham, the First Assistant at the observatory, retired. Mr. Graham had been at the observatory for forty-seven years. He was succeeded by Mr. H. W. Wood, M.Sc.

Mr. E. E. Adderley, B.Sc., was appointed to the position of Assistant Astronomer.

Dominion Observatory, Wellington, New Zealand
(Acting-Director, R. C. Hayes)

Time Service.—This observatory has continued to control the time service for New Zealand, time-signals having been sent out as in previous years. On 1st June, a six-dot form of signal, similar to that supplied by Greenwich Observatory to the British Broadcasting Corporation, was

adopted for the time-signals to the New Zealand National Broadcasting Service.

Solar Work.—Solar observations have been carried on as in previous years by Mr. I. L. Thomsen, using the 5-inch refractor of the Wellington Philosophical Society's Observatory. Results of solar observations are sent to Zürich, and reports are published by the Solar Section of the New Zealand Astronomical Society. Some solar observations were also made by Mr. M. Geddes in Southland, with the 5-inch refractor on loan from this observatory. Mr. Thomsen made a study of solar phenomena, and during the year published a paper in the *Journal of the Royal Astronomical Society of Canada* on the probable existence of an area of maximum activity on the Sun. A paper by I. L. Thomsen and M. Geddes, incorporating the results of a preliminary study of solar and terrestrial relationships, was also prepared for publication. Mr. Thomsen carried out a considerable amount of work in connection with the measurement of the plates of the Solar Eclipse of 1937 June 8. The photographic densities of a number of points on the plates are being measured photometrically. Preliminary reductions show that the brightness of the inner corona varies inversely as the fourth power of the distance from the Sun's centre.

Occultations.—Observations of occultations have been continued by officers of this observatory, in co-operation with the Wellington City Observatory, the New Zealand Astronomical Society, and the New Plymouth Astronomical Society. The observations are sent to the Computing Section of the British Astronomical Association.

Auroral Work.—Observations of the aurora australis have been carried on in Southland under the direction of Mr. M. Geddes. The observing facilities were much improved early in the year by the installation of radio as the means of communication between the two observing stations. Auroral activity was high during 1938. In addition to numerous minor displays, prominent auroræ were observed on Jan. 22, 25, 26, Mar. 22, 23, 24, Apr. 16, 23, May 29, July 15, 30, Aug. 4, Sept. 15, 26, and Oct. 25. The display of September 15 was probably the most remarkable, although not the brightest, display yet observed in New Zealand. The main aurora was of a normal type, but for about one hour an extremely rare type of high arc developed north of the zenith. Such arcs have been recorded on eight occasions since 1870 in the Northern Hemisphere, but not previously, as far as can be traced, in the Southern Hemisphere. During the year, 1130 successful photographs of auroræ were made with the special aurora cameras. These included 193 simultaneous pairs for the determination of the heights of auroræ. Mr. Geddes has made good progress with the laborious work of measuring the aurora plates, and a paper dealing with the results for the year 1937 is now in the press. Reports on the aurora work are forwarded to Professor Störmer, Norway, and summary reports are published locally by the New Zealand Astronomical Society.

Publications.—The only astronomical matter published directly by this observatory during the year was contained in *Bulletin* No. 135—"Report on the Activities of the Dominion Observatory for the year 1937."

General.—This observatory co-operates with the New Zealand Astronomical Society in directing astronomical research work in New Zealand.

Dr. C. E. Adams, formerly New Zealand Government Astronomer and Seismologist, and Director of this observatory, retired in 1936 April. Dr. Adams was Government Astronomer from 1912 until his retirement in 1936, and Government Seismologist from 1920.

Mr. Robert Barker's Observatory, Cheshunt, Herts

Critical lunar observations continued on Plato, Aristarchus and other defined areas seem to confirm the belief that cyclical periods, or seasons, of vegetation actually occur with varying intensities.

Evidence of lunar mist, or obscuring medium, has been obtained on several occasions.

On the whole, observing conditions throughout the year have been unfavourable.

Mr. Evershed's Observatory, Ewhurst, near Guildford

Spectroheliograms in $H\alpha$ light for the estimation of character figures were obtained on 98 days during the year, and the results have been communicated to Dr. Brunner. Bright eruptions on the disc were recorded on these plates on 15 days. A list of these, and of the times when the Sun was under observation, have been sent quarterly to the Meudon Observatory for inclusion in the *Bulletin of Character Figures.*

Prominence photographs in $H\alpha$ light were obtained on 50 days, and 17 prominence spectra have been photographed and measured.

The liquid prism spectrograph has been employed in photographing the sodium D lines with 10, 12 and 14 transmissions through the prism, and with vacuum tube comparison. The precise interval between D1 and D2 has been measured in Sun and tube, the result being 5·973 in the Sun and 5·974 in the vacuum tube, from 5 west-limb spectra where the atmospheric line on the red edge of D2 does not interfere with the measures. In the Revision of Rowland it is 5·967, a value probably affected by the atmospheric line. The pair of sodium lines in the green at 5682 and 5688 has also been photographed with vacuum tube comparison for measuring the shift of these lines in the Sun.

A series of photographs of spot spectra on the green region with 10 transmissions through the prism has revealed a striking example of a Zeeman doublet at 5250·2, which does not appear to have been observed by Hale in his researches on the magnetic field in spots or in the general magnetic field of the Sun.

In the H and K region new measures have been made of these two lines, and of some others, with high-dispersion spectra obtained with four transmissions through the prism. The results have been communicated to the Society.

Dr. J. L. Haughton's Observatory, Teddington

Owing to improved weather conditions, more than twice as many occultations were observed this year as in 1937, the number seen being twenty-two.

The nova search photographs were continued, and the aurora of January 25–26, and what was visible through clouds of the lunar eclipse of November 7, were observed.

Mr. M. B. B. Heath's Observatory, Kingsteignton, Devon

The exceptional aurora of January 25 was well observed.

Daylight observations of Mercury were made on 32 days, and of Venus on 30 days. All results were communicated to the British Astronomical Association.

Mr. F. M. Holborn's Observatory, Streatham

Observations were made on 185 nights in 1938. 13 visual estimates of brightness were made of Nova Herculis (1934) and 11 of Nova Lacertæ (1936). Gamma Cassiopeiæ was observed on 120 nights. 2684 observations were made of 63 variable stars. The Sun was observed on 196 days, on 120 of which one or more naked-eye spots were seen.

The auroræ of January 25 and May 11 were observed.

Records of all the above were communicated to the British Astronomical Association.

Mr. A. M. Newbegin's Observatory, Worthing, Sussex

During the year 1938 a total of 111 observations were made of prominences and 116 of sunspots. The mean daily frequency for the former was 13·30 and for the latter 7·90.

Prominences maintained their preponderance in the northern hemisphere, the percentage north being 54·4, and a slight excess on the east limb was noticeable. Metallic activity was recorded in 57 prominences, but very few were of class 3, in which a large number of lines are seen.

Sunspots were slightly in excess south of the equator for the whole year, but there were fluctuations between the two hemispheres and in April the south predominated by as much as 75 per cent. A number of groups were visible to the naked eye, but the number was less than in the previous year. A high peak of sunspot activity occurred in July–August, the mean daily frequency then being 10·22.

Observations with the spectrohelioscope numbered 102 and 135 bright chromospheric eruptions were recorded, details of which have been sent to

M. d'Azambuja at Meudon for inclusion in the Zürich *Bulletin* issued by the I.A.U.

Measurements of the displacement of the *Hα* line were observed in a number of eruptive prominences, both at the limb and on the disc. The most interesting of these were two prominences seen at the limb on January 24, the day preceding the great aurora, and another on August 9. In the first case the prominence reached a height of 200″, and velocities of from −95 to +116 km./sec. were recorded. In the latter case the prominence was 360″ high, with velocities of from −52 to +80 km./sec. An interesting feature of these two prominences was that the January display was in lat. E. +14° to +30°, long. 235°, and the co-ordinates of the prominence of August 9 were lat. E. +17° to +38°, long. 334°.

Dark flocculi associated with sunspots were observed as often as time permitted, the greatest outwards velocity recorded being −205 km./sec., and inwards +150 km./sec.

The 9-inch Coudé telescope, in the hands of Mr. Bernard Pitcher, has been in use for general work so far as his duties at the University of Bristol permitted, and a number of observations of sunspots were made.

Mr. B. M. Peek's Observatory, Solihull, Birmingham

Photometric observations of Nova Persei 1901, U Geminorum and SS Aurigæ have been continued.

Thirty-six occultations of stars by the Moon were recorded in 1938, 9 of them during the lunar eclipse of November 7.

The declination of Jupiter having become somewhat more favourable for northern observers, far more work was accomplished on the physical features of the planet's surface than during the last three apparitions.

The reduction of longitude observations, made by members of the Jupiter Section of the British Astronomical Association, and the determination of rotation periods have been continued, and the work is now complete to the end of 1936.

Rev. T. E. R. Phillips's Observatory, Headley

Routine work has been carried on as in previous years.

Over 1400 central meridian transits of markings on Jupiter were secured during the past apparition of the planet, and the 29th Report of the Jupiter Section dealing with the apparitions of 1931–32 and 1932–33, and summarizing the main results obtained since 1901 (30 apparitions), has been presented to the British Astronomical Association and is now in the press. Observations have also been made of Saturn, which has recently shown considerable changes in the intensity of the belts and zones.

The measurement of double stars with the 8-inch refractor lent by the

Society has been continued, special attention being given, at the request of Dr. R. v. d. R. Woolley, to certain pairs showing—or suspected of showing —orbital motion.

Owing to illness Dr. Waterfield has not yet been able to resume regular observation. Nevertheless he obtained a photograph on a blue sensitive plate of the totally eclipsed Moon on November 7, together with comparison images of the Full Moon. This plate when measured should give a satisfactory determination of the relative brightness of the totally eclipsed Moon and Full Moon.

Two photographs were also obtained of Peltier's Comet and its position determined.

Since the Stockholm meeting of the International Astronomical Union in August, Mr. P. M. Ryves has been at Headley working on variable stars.

Mr. F. J. Sellers's Observatory, Muswell Hill, London

Daily observations of sunspots and prominences have been made when possible (215 days) during the year with the 5-inch equatorial and of solar-disc phenomena with the spectrohelioscope. From the summaries of these observations published in the *B.A.A. Journal* it appears that solar activity has been near maximum during the year. The highest sunspot frequency was recorded between May and August.

Whenever possible, spectrohelioscopic observations have been made from 7^h to 8^h, as well as at other times, and 32 bright chromospheric eruptions during the year have been reported to Meudon for inclusion in the I.A.U. tables.

This work has been greatly helped since the installation in August of a larger diffraction grating, lent by the Society, which has increased the capacity of the instrument.

Dr. W. H. Steavenson's Observatory, West Norwood

Observations were made on 76 nights during the year.

The $20\frac{1}{2}$-inch Hindle reflector was used mainly for the observation of faint variable stars and novæ.

163 observations of 12 old novæ were made, and some of these have been communicated to the Society.

43 observations of 3 irregular variables have been communicated to the Variable Star Section of the British Astronomical Association.

The mirrors of the telescope were resilvered on November 6.

The great development of street lighting in London during recent years has proved an increasingly serious handicap in the observation of faint objects, and only the more transparent nights are now suitable for such work.

Wolsingham Observatory (*Rev. T. E. Espin's*), *Tow Law, Co. Durham* (*Observer, W. Milburn*)

The usual programme of remeasurement of certain known double stars, chiefly those discovered at this observatory, has been continued with the 24-inch Calver reflector, together with the survey for new double stars in the unexamined parts of the B.D. zones $+25°$ to $+35°$. The results have been communicated to the Society.

The 5-inch Troughton & Simms' refractor, on equatorial mounting, has been erected in a revolving hemispherical dome. It has been found useful for the observation of objects outside of the range of the reflector and for visitors.

REPORTS ON THE PROGRESS OF ASTRONOMY

STELLAR MOTIONS

The domain of stellar motions has not recently yielded striking new aspects. Nevertheless, important advances have been made, which, in the following, will be illustrated by some typical examples, while it will also be attempted to give a brief survey of present knowledge. The principal new data of observation which have become available in the last few years are summarized in the first section. It is to be noted that the present review is not, even approximately, to be considered as a complete report on the very great amount of work done in this field in recent years.

A very complete and welcome survey of the methods used in the discussion of stellar motions and the dynamics of star-systems has just become available in Smart's book on *Stellar Dynamics* (Cambridge, 1938). The same subject has likewise been treated in von der Pahlen's extensive *Lehrbuch der Stellarstatistik* (Leipzig, 1937), which also contains ample information on the results of observation.

I. *Observations*

By the preparation of the *Dritter Fundamentalkatalog des Berliner Astronomischen Jahrbuchs* * a considerable improvement has been achieved in the accuracy of fundamental proper motions.

A vast material of new data on proper motions has become available through the publication, in 1938, of the General Catalogue prepared at the Dudley Observatory, Albany, and containing the motions of 33,342 stars (among which are all those brighter than the seventh magnitude).

For fainter stars the material obtained by the re-observation of the *Astronomische Gesellschaft Catalogues* is gradually increasing. For the parts of the sky from $-2°$ to $+1°$, $+20°$ to $+30°$ and $+50°$ to $+60°$ declination the repetition has been completed and published by the Yale Observatory. These catalogues give proper motions of about 40,000 stars, complete to $9^{m}{\cdot}0$ BD, and with probable errors ranging from $\pm\ 0''{\cdot}005$ to about $\pm\ 0''{\cdot}010$ according to the declination zone. The Astronomische Gesellschaft, which has taken up the entire re-observation of the northern hemisphere, is making rapid progress ; the Yale Observatory has completed the reductions for the zones between $-10°$ and $-20°$, and is working on the zones from $-2°$ to $-10°$ and $-20°$ to $-30°$. The part of the sky south of $-30°$ is being observed by the Cape Observatory, which has already published a catalogue of rather accurate proper motions for 20,000 stars down to $9^{m}{\cdot}5$ CPD and situated between $-40°$ and $-52°$ declination.† The whole

* I. Teil : *Veröff. Astr. Rechen-Inst.*, Nr. 54, 1937 ; II. Teil : *Abh. Preuss. Ak., Phys.-math. Klasse*, Nr. 3, 1938.

† *Proper Motions in Zone Catalogue*, Royal Observatory, Cape of Good Hope, 1936.

repetition, when finished, will yield the proper motions of some 200,000 stars.

A large amount of work has been done on the proper motions of still fainter stars. Van de Kamp and Vyssotsky* have determined proper motions of 18,000 stars in 341 small regions, down to an average limiting magnitude of 12·4 visual. The average probable error is ±0″·0057 for the relative motions. Each field was centred on a bright star, selected from Boss's P.G.C., and usually reduced to the tenth magnitude by a rotating sector; by the aid of the known proper motion of this star the motions of the faint stars were reduced directly to the system of the General Catalogue. A second, still considerably larger undertaking was that of the determination of about 33,000 proper motions at the Radcliffe Observatory,† started as part of Kapteyn's Plan of Selected Areas. The Radcliffe Catalogue contains very accurate motions (average probable error ±0″·0037) for stars down to $15^{m}\cdot0$ to $15^{m}\cdot5$ pg. In this case it is the *relative* motions to which the greatest importance should be attached.

Our knowledge of large proper motions has been very greatly enlarged by Luyten's exhaustive survey on the Harvard Bruce plates.‡ This survey, which covers almost the entire southern hemisphere, has yielded over 90,000 proper motion stars. The reductions have been completed for the declinations south of −55°, while in addition all motions in excess of 0″·45 per annum have been reduced. The latter material is practically complete to $14^{m}\cdot5$ pg.; part of the data are complete even to $16^{m}\cdot5$. The individual data have not yet been published. For stars down to about $18^{m}\cdot0$ Oosterhoff§ has published a list of 651 proper motions found on Mt. Wilson plates of the Selected Areas.

Since the appearance of Moore's General Catalogue,‖ radial velocities have been published for about 2000 stars not contained in that catalogue, in addition to duplicate observations for many other stars. The most interesting additions relate to special types of stars, such as δ Cephei and RR Lyrae variables, R- and N-type stars, early-type stars showing interstellar lines, and to the nebulæ.

The following list comprises, I hope, all the more extensive publications containing radial velocity data not included in Moore's catalogue.

R. O. Redman, "The galactic rotation effect in some late-type stars," *Publ. Dominion Obs. Victoria*, **6**, 27, 1931.

V. A. Albitsky and G. A. Shayn, "Radial velocities of 343 stars," *Publ. Poulkovo*, II/**43**, 1933.

W. E. Harper, "The radial velocities of 477 stars," *Publ. Dominion Obs. Victoria*, **6**, 151, 1933.

R. F. Sanford, "Radial velocities of the stars of spectral classes R and N," *Ap. J.*, **82**, 202, 1935; *Mt. Wilson Contr.*, No. 525.

* *Publ. McCormick Obs.*, **7**, 1937.
† *Radcliffe Catalogue of Proper Motions in Selected Areas*, 1934.
‡ *Publ. Obs. Minnesota*, **2**, No. 5, 1938.
§ *Ap. J.*, **83**, 340, 1936; *Mt. Wilson Contr.*, No. 542.
‖ *Lick Publ.*, **18**, 1932.

F. K. Edmondson, "The motions of the globular clusters and the galactic rotation," *A.J.*, **45**, 1, 1935 (contains unpublished velocities for 8 globular clusters, measured by Humason and Slipher).

M. L. Humason, "The apparent radial velocities of 100 extra-galactic nebulæ," *Ap. J.*, **83**, 10, 1936; *Mt. Wilson Contr.*, No. 531.

W. E. Harper, "The radial velocities of 917 stars," *Publ. Dominion Obs. Victoria*, **7**, 1, 1937.

P. W. Merrill, R. F. Sanford, O. C. Wilson and Cora G. Burwell, "Intensities and displacements of interstellar lines," *Ap. J.*, **86**, 274, 1937; *Mt. Wilson Contr.*, No. 576.

A. H. Joy, "Radial velocities of Cepheid variable stars," *Ap. J.*, **86**, 363, 1937; *Mt. Wilson Contr.*, No. 578.

R. F. Sanford and P. W. Merrill, "Radial velocities of some early-type stars," *Ap. J.*, **87**, 517, 1938; *Mt. Wilson Contr.*, No. 591.

W. H. Christie and O. C. Wilson, "The radial velocities of 600 stars and measures of 69 spectroscopic binaries," *Ap. J.*, **88**, 34, 1938; *Mt. Wilson Contr.*, No. 593.

W. S. Adams and A. H. Joy, "A list of stars with unpublished radial velocities greater than 75 km./sec.," *P.A.S.P.*, **50**, 214, 1938.

A. H. Joy, "Radial velocities of 67 variable stars of the RR Lyræ type," *P.A.S.P.*, **50**, 302, 1938.

H. Mineur, "Sur la rotation galactique des amas ouverts, etc.," *Ann. d'Astrophysique*, **1**, 269, 1938 (contains some unpublished velocities of open clusters, measured by Trumpler).

At Harvard, Bok and McCuskey have given a new impetus to the determination of radial velocities of B-, A-, and F-type stars by means of objective prisms and neodymium screens.* They have succeeded in improving the accuracy of these velocities; their further development of this method, which may prove of much importance for the exploration of the galactic system, is awaited with considerable interest.

II. *Interpretation of Observations*

Solar Motion and Differential Motions.—The determination of the Sun's motion from radial velocities has been the object of numerous investigations. I will mention only the study by Nordström † as the most comprehensive work on this subject, in which much material has been added which was not available at the time when Mineur and his collaborators published similar investigations.‡ The motion of 20 km./sec. towards $\alpha = 18^h\ 0^m$, $\delta = +30°$, which has often been adopted as a standard, has been generally confirmed. The different types of stars show slightly varying values, but the deviations may well be of accidental character, except possibly for the bright B-stars, and also for dwarfs and special types of stars where the asymmetry of the high velocities causes systematic deviations.

* *H.A.*, **105**, 327, 1937.
† *Lund Meddel.* II, No. 79, 1936.
‡ *B.A.*, **6**, Fasc. 9, and **7**, Fasc. 8.

In studies of solar motion stars in different parts of space are now often studied separately, in order to determine the relative systematic motions of different parts of the galactic system. These systematic motions have usually been found consistent with a rotation of the galaxy around a centre in 325° longitude, though there are certainly some local deviations from this simple scheme. The most notable of the local deviations is perhaps that connected with the so-called K-term of the bright B-type stars. Nordström, for example, finds from 464 Oe5 to B5-stars K = 4·6 km./sec. ±0·3 (p.e.).* According to Plaskett and Pearce † the systematic error due to relativity shift will be only + 1·3 km./sec., so that an unexplained motion of + 3·3 km./sec. remains. After correcting the B-star motions for the solar motion as usually adopted for the bright stars in general, Plaskett and Pearce noted that especially large positive deviations remained in the region of the great southern group of B-type stars between 210° and 330° longitude, which had previously been studied by Kapteyn. This group, which includes the so-called Scorpio-Centaurus cluster, would have a systematic motion of about 8 km./sec. with respect to the centroid of the bright stars, and this would be the main cause of the large K-effect and of the somewhat deviating solar motion found for the B-stars. The existence of local systematic motions differing slightly from the general average would not be surprising in view of the existence of the pronounced inequalities in the space distribution of these early-type stars.‡ According to computations by Smart, Nordström and by Lall §, who remark that the vertex was not derived correctly, there would be a considerable difference between the group motion as indicated by the proper motions on one hand and the radial velocities on the other hand, so that they reject the stream. However, as it is well known that considerable systematic errors may exist in the southern proper motions, the objections made to Plaskett and Pearce's plausible explanation of the K-term may, after all, not be insuperable.

The investigations at Victoria on early-type stars and interstellar gas, which were concluded by the publication of the general study of the motions of O- and B-stars just quoted, constituted a very considerable gain in our knowledge of relative motions in the galaxy. The same can be said of Merrill and Sanford's ‖ recent investigation of the interstellar gas, in which numerous new observations of distant stars have been added, the velocities being derived from the K-line of Ca^+ as well as from the D-lines of sodium. The most distant group of stars included is at about 2000 parsecs (*cf.* fig. 3, *loc. cit.*).

The most important contribution has been made by Joy ¶ who has studied the velocities of 128 δ Cephei variables. In his most distant group

* *Loc. cit.*, p. 90. *Cf.* also Mineur and Guintini, *B.A.*, **8**, 255, 1934.

† *Publ. Dominion Obs. Victoria*, **5**, No. 4, p. 277, 1936.

‡ It is to be noted that the effect of this group would naturally divide itself over the solar motion and the K-term.

§ *M.N.*, **99**, 42, 1938.

‖ *Ap. J.*, **87**, 118, 1938; *Mt. Wilson Contr.*, No. 585.

¶ *P.A.S.P.*, **45**, 202, 1933. Individual data in *Ap. J.*, **86**, 363, 1937; *Mt. Wilson Contr.*, No. 578. See also *Publ. Kapteyn Lab. Groningen*, No. 47, p. 3.

the systematic deviations from the motion of the stars near the Sun run up to values from 40 to 55 km./sec. Three out of the four longitudes with maximum deviation are covered by the observations; the variation with the longitude agrees very well with the double sine-curve of ordinary differential rotation.

The data of differential rotation so far available had mostly been derived from types of stars showing a strong concentration towards the galactic plane and having small peculiar motions; the only exceptions were formed by the planetary nebulæ and the N-type stars. The data available for the latter were, however, so meagre as to be of little significance. Quite recently these have been very considerably extended through the work of Sanford,* who finds good evidence of the galactic rotation among these rather distant stars.

Summarizing that part of our knowledge concerning the systematic motions in the galactic system which appears to be firmly established, we may state that up to the distances of the farthest Cepheids observed, that is, to an average distance of about 2500 parsecs in the galactic plane, the observed motions are well represented by the first order terms of the differential galactic rotation. Though the most southern part of the sky contains only few observations, the interval from 271° to 193° longitude, or nearly 80 per cent. of the galactic circle, including the four regions of maximum differential effect, is well covered.

From a purely kinematical point of view the observed differences in radial motion can, of course, be interpreted in different ways (see articles by Pilowski,† Mineur,‡ Ogrodnikoff§ and Milne‖). But, if the knowledge of these differential motions is combined with all other knowledge about the galactic system, the interpretation as the effects of a simple rotation around the centre of this system appears to be the most probable. But for some minor deviations which are plausibly described to local irregularities, all the facts observed are well represented by this model. So far as present observations of systematic motion go, there do not appear to be any well-defined effects for which a generalization of the simple representation would be required.

In this connection it should be mentioned that in discussions of radial velocities of bright stars Mineur and others have previously found evidence of a change of the systematic motion with the positions of the stars with respect to the galactic plane. The same phenomenon is found in Nordström's article, the apex derived from stars of northern and southern latitudes differing by about 14° (*loc. cit.*, Table 22 and p. 109). However, as no corresponding shift is found in the space velocities it is doubtful what significance can be attached to the phenomenon.

From a combination of existing data on rotation Plaskett and Pearce (*loc. cit.*, p. 281) derive $325°{\cdot}4 \pm 1{\cdot}1°$ (p.e.) for the *longitude l_0 of the centre* of rotation. Adding Joy's determination, $l_0 = 324°$, and the value $l_0 = 329°$

* *Ap. J.*, **82**, 202, 1935; *Mt. Wilson Contr.*, No. 525.
† *Zs. f. Ap.*, **3**, 53, 279, 291 and **4**, 396, 1931–32.
‡ Cf. *B.A.*, **5**, 505, 1929.
§ *Zs. f. Ap.*, **4**, 190, 1932.
‖ *M.N.*, **95**, 560, 1935.

found by Merrill and Sanford, to the list given by the Victoria observers, there appears to be very strong evidence for the identity of the rotational centre and the material centre of the galactic system. The longitude of the latter can be found in two entirely different ways: in the first place from the distribution of globular clusters, from which it is estimated as $325° \pm 2°$ (p.e.); in the second place from the distribution of faint stars at great distance from the galactic plane, which gives $324° \pm 3°$ (p.e.).* The close agreement is important, as it indicates that the systematic motions are perpendicular to the radius vector, and not inclined, as they would be in case they followed spiral orbits. The longitude derived also agrees with the direction perpendicular to the systematic motion of objects of high velocity, for which Strömberg † found 331°, and Oort 325°,‡ the p.e. being estimated at about $\pm 3°$ in each case.

The *distance to the centre*, R_0, can best be estimated from the distribution of globular clusters. If the effect of absorption is taken into account and the evidence is combined with that derivable from the motions of globular clusters, nebulæ and other high velocity objects, it may, in my opinion, be safely concluded that the distance is not less than 6000 and not more than 10,000 parsecs. Provisionally, we might adopt $R_0 = 8000$ parsecs.

As regards *the constant A*, various determinations yield considerably different results. The determination is complicated by the fact that fundamental distances are needed to find the constant. These distances can only be derived from proper motions, which are reliable only for the nearer groups of bright stars where the effect of the rotation is small and disturbed by local motions. The method followed, then, is to estimate mean distances of the fainter groups by assuming that the mean absolute brightness is the same as, or can be derived from, that of the bright groups. But here a new difficulty comes in, as the light of the distant stars is dimmed by absorption. In Plaskett and Pearce's work the absorption has been neglected. Introducing an average absorption of $1^m.0$ (visual) per 1000 parsecs between the bright and faint groups used by these authors, a weighted average $A = .0182$ km./sec. parsec is found from their Tables 21 and 22. This agrees closely enough with independent values derived from δ Cephei variables by Joy ($A = .0185$) and from *c*-stars brighter than $5^m.8$ ($A = .023$). Determinations from proper motions only, yield an uncertain, but entirely independent value of $0''.0026$ or 0.0123 km./sec. parsec.§ We may provisionally adopt $A = .018$.

For the constant B we might adopt -0.013 km./sec. parsec or $-0''.0027$, as derived directly from proper motions (see below) as well as from the ratio of the galactic axes of the velocity-ellipsoid.‖ The resulting angular velocity

* *B.A.N.*, **8**, 263, 1938.

† *Ap. J.*, **61**, 377, 1925; *Mt. Wilson Contr.*, No. 293.

‡ *B.A.N.*, **4**, 270, 271, 1928.

§ Average of determinations by Plaskett and Pearce, *loc. cit.*, Oort, *B.A.N.*, **4**, 86, and Wilson and Raymond, *A.J.*, **47**, 56, 1938.

‖ *Cf.* the complications in *B.A.N.*, **8**, 154, 1937, and in *A.J.*, **47**, 56 (Wilson and Raymond).

of rotation $B - A$ is $-0''.0065$, while the average rate of change of the circular velocity Θ_c with distance to the centre, $\partial\Theta_c/\partial R = -A - B$, is -0.005 km./sec. parsec.

The linear *velocity of rotation* is equally uncertain as the distance to the centre. With the angular velocity just adopted the value corresponding to $R_0 = 8000$ parsec would be 248 km./sec. The latest direct determination from 26 globular clusters by Edmondson* gives 274 km./sec. $\pm$ 40 (p.e.), while from the nearest extra-galactic nebulæ a value of 365 ± 70 (p.e.) has been derived. An entirely independent determination may be obtained from a combination of the rate of decrease of density with R in the system of globular clusters, and the average peculiar velocity of these objects. Using Edmondson's data for the average peculiar velocity and van de Kamp's data † for the density gradient the acceleration near the Sun may be estimated at 2.5×10^{-8} cm./sec.^{2}, from which we derive $\Theta_c = 250$ km./sec. This estimate is admittedly uncertain, but the uncertainty is probably not larger than that of the more direct determinations.

The problem of *second-order terms* in the differential rotation has been discussed by several authors. It may be useful to make a distinction between two causes determining the appearance of these terms. In a system with rotational symmetry deviations from the simple double-harmonic formula will firstly occur for geometrical reasons, the zero-points of the differential velocity near 55° and 235° longitude being shifted in the direction of the centre of the system. If this shift is denoted by ϕ we have evidently $\sin\phi = r/R_0$, where r is the distance of the stars considered. The shift is, of course, independent of the way in which Θ_c varies with R. Deviations from linearity in the latter variation will show themselves primarily as differences in the amplitude of the rotational term between the quadrants near the centre and those near the anti-centre. It is not possible to predict in which direction the difference would go. Moreover, for the present, it seems a hopeless task to approach this latter effect from the observational side, as any observed asymmetry of the kind mentioned might as well be ascribed to a systematic difference in absorption between the centre and the anti-centre regions. As regards the shift ϕ, this would amount to about 9° for the most distant group of stars for which somewhat precise data are accessible (Joy's faintest Cepheids); a shift in the right direction seems indeed to be indicated in this case for the zero-point near 55° longitude, but the data are insufficient to make a significant estimate of the amount. We may conclude that, even for the Cepheid data, there is not much need for introducing second- or higher-order terms. For the open clusters the situation is decidedly less favourable for finding evidence of these higher-order terms.

It is possible that higher-order effects are present in the motions of the planetary nebulæ, but the interpretation of this case is still uncertain. Ogrodnikoff, treating all nebulæ together without separating them according to distance, finds evidence of fairly small second-order terms,‡ but as the

* *A.J.*, **45**, 2, 1935. † *A.J.*, **42**, 161, 1933.

‡ *Poulkovo Circ.*, No. 21, 1937.

individual velocities are large and the number of objects small, the determination is admittedly uncertain. Berman,* and more recently Camm,† have separated the nebulæ according to their distance. Berman derives distances which for many of these nebulæ are of the order of 10,000 parsecs or more, thus extending to the galactic centre and beyond. These large distances would be confirmed by the radial motions. It is clear that these results, if substantiated, might yield information of the greatest importance concerning the structure of the galactic system. Berman has taken pains to discuss very carefully all data at his disposal. However, the main argument leading to these very large distances, viz. the practical identity in absolute magnitude and dimensions of the faint and bright planetaries, combined with the assumption that the diameters are not influenced by galactic absorption, is not convincing. It may be remarked that the observed radial velocities for each of Berman's 4 groups can be practically equally well represented upon the assumption of much smaller distances, for which only first-order terms would be relevant. If, on this assumption, the mean distances are derived in the usual manner from the coefficient of $\sin 2(l-l_0)$, values of 1200, 1700, 1700 and 3700 parsecs are found for Berman's first 4 distance groups,‡ while Berman derives 854, 2638, 4722 and 9130 parsecs respectively. Similar objections may be made against Camm's discussion. There is also other evidence indicating that the distances assumed are too large. The case is evidently uncertain.

Motions of Objects of High Velocity.—Radial velocities for 67 RR Lyræ variables have been published by Joy§; by this publication the number of known velocities has been increased by 150 per cent. From the new data the following constants for the solar motion may be derived: 130 km./sec. ± 14 (p.e.) directed to $\alpha = 297°$, $\delta = +52°$ or $l = 53°$, $b = +12° \pm 8°$ (p.e.). The direction agrees well with that of the rotation. The average residual velocity of ± 69 km./sec. is nearly as large as that of the globular clusters. Some of the stars appear to possess exceptionally high velocities, ranging up to 400 km./sec. with respect to the galactic centre. With improved values for the proper motions, which will be available in the near future, these stars may give interesting information in yielding a lower limit for the velocity of escape from the galactic system.

* *Lick. Bull.*, **18**, 57, 1937. † *M.N.*, **99**, 71, 1938.

‡ The use of radial velocities for estimating the distances is criticized by Camm. We may note, however, that the values of the coefficient, $\bar{r}A$, are of the same order as those found by Joy for the faint δ Cep variables (see *Publ. Kapteyn Lab. Groningen*, No. 47, p. 3). The latter data, which are considerably more accurate than those for the planetaries (on account of the smaller peculiar velocities and the better knowledge of absolute magnitudes), indicate clearly that the corresponding distances are still small compared with the distance to the centre. Using a reasonable estimate of the absorption they also indicate that up to the $\bar{r}A$-values concerned this coefficient varies in an approximately linear way with the distance, and is, therefore, probably a reliable indicator of the mean distance.

In the case of the planetaries some uncertainty arises, however, from the circumstance that the peculiar velocities are fairly high, so that the systematic motions might differ somewhat from the circular motions.

§ *P.A.S.P.*, **50**, 302, 1938.

Distribution of Peculiar Motions.—The motions of the bright stars have been treated by various authors. Perhaps the most important fact, long known, but strongly confirmed by recent investigations, is the deviation of the major axis of the velocity-ellipsoid from the direction to the centre of the galactic system. From an investigation of the radial velocities of stars brighter than $6^{m}.0$ Nordström, for instance, finds $340° \pm 3°$ (p.e.) for the longitude of the vertex. The earlier determinations from proper motions had given 346°, thus deviating still more from the adopted centre. There can be not much doubt that this deviation is real. There are indications, however, that the fainter dwarfs do not show it; according to an unpublished investigation by Veldt of the space motions of the nearest stars, the longitude for dwarfs fainter than $+5^{M}$ is found at $326° \pm 1°$ (p.e.). A similar direction seems to be indicated by the preferential motion among high-velocity objects.

The inequality in the distribution of the stars over the two streams, which was found by Eddington in his analysis of the Boss stars, has not been confirmed from radial velocities (see an article by Smart).* Nor has a similar inequality been found among fainter stars.

A new feature found in Nordström's paper is that the peculiar motions of faint O–B5-stars, contrary to those of bright stars of these types, show a decidedly ellipsoidal distribution, the ratio of the two galactic axes being 0·59, and the major axis pointing to 304° longitude. It should be noted, however, that the phenomenon is complicated, in this case, by the large effects of galactic rotation.

The most important advance has come from investigations of faint stars. Among other investigations we may mention Know-Shaw and Scott Barrett's discussion of the Radcliffe motions,† and van de Kamp and Vyssotsky's study of motions of stars on parallax-plates.‡ Smart and Tannahill § have added new material to the notable investigations in this direction published at the Cambridge Observatory in the past. Stenquist ‖ has determined magnitudes, spectra and luminosities for faint stars in the Cambridge regions, and has discussed the motions in relation to these new data. Luyten has published an investigation of 85,000 faint southern stars with motions exceeding $0''.050$ per annum.¶ Jackson** has analysed a large material of proper motions down to $10^{m}.5$ pg. in the zone $-40°$ to $-52°$.

From these investigations, in particular from that by Knox-Shaw, which extends to 15^{m}, it has become once more clear that the phenomenon of star-streaming extends unaltered up to large distances (up to 1500 parsecs for the Radcliffe data). The vertex derived from the faint stars shows a similar deviation from the direction of the centre as that from bright stars,

* *M.N.*, **96**, 165, 1936.
† *Radcliffe Catalogue of Proper Motions in the Selected Areas 1 to 115*, 1934.
‡ *Publ. McCormick Obs.*, **7**, 1937.
§ *M.N.*, **98**, 563, 1938.
‖ *Upsala Meddel.*, No. 72, 1937.
¶ *H.A.*, **105**, 397, 1937.
** Proper Motions in the Zone Catalogue of 20,843 stars observed at the Royal Observatory, Cape of Good Hope, 1936.

though the amount of the difference becomes probably somewhat smaller. For stars from $9^m.0$ to $14^m.0$ the Radcliffe Catalogue gives a mean vertex at $l = 336°$, $b = -4°$, for stars between $14^m.1$ and $15^m.0$, $l = 332°$, $b = +1°$, with p.e.'s of not more than $\pm 2°$. Using mean proper motions instead of the distribution of position angles Blaauw * derived $l = 322°.7 \pm 2°.3$ (p.e.) from the same material. Van de Kamp and Vyssotsky, with rather brighter stars, find, however, $l = 346°$, $b = +4°$. From the Cambridge regions Smart and Tannahill find $l = 337°$, $b = -1°$; the material extends perhaps to 12^m pg.

Van de Kamp and Vyssotsky, as well as Jackson, have found independently that the longitude of the vertex derived from stars at high galactic latitude is about 10° lower than that for stars near the galaxy.

The ratio of the axes of the velocity-ellipsoid has been found to be about the same as that determined from bright stars. After correcting roughly for the influence of accidental errors van de Kamp and Vyssotsky found 0.63 for the ratio of the major axis to the average of the two other axes. Similarly, from the Radcliffe material, Blaauw found $0.60 \pm .03$ (p.e.) for the ratio of the two galactic axes.

From the Radcliffe motions another new point of much interest for dynamical considerations may be inferred, namely, that for regions near the galactic plane the average peculiar velocity does not appear to vary in an important degree throughout the large part of the galactic system covered by these observations.†

Motions in Interstellar Gas.—It has been shown by Beals ‡ that the interstellar lines in ρ Leonis as well as in ϵ and ζ Orionis are double. The result holds both for sodium and calcium, which show identical values for the individual velocities of the two main clouds that are apparently involved, the difference in velocity between the two clouds being respectively 29, 14 and 26 km./sec. Similar differences, ranging up to values of 47 and in one case even 68 km./sec., have been reported by Sanford, Merrill and O. C. Wilson § for seven other stars. It was already known that in some cases the interstellar gas exhibits a peculiar velocity which cannot be due to galactic rotation. Also, this gas appears to extend to considerable distances on both sides of the galactic plane,‖ differing in this respect rather radically from the early-type stars, and perhaps resembling more nearly the distribution of late-type giants. This also indicates that there must be fairly large peculiar velocities in the gas. The general existence of separate clouds with considerable peculiar motions may also be concluded from the fact that at greater distances the intensity-ratios in the doublets, D_2/D_1 and K/H, are much smaller than 2, while at the same time the absolute intensities appear to increase linearly with the distance, and show no variation with galactic longitude. The interpretation of these facts with the aid of separate clouds

* *B.A.N.*, **8**, 311, 1939.

† *B.A.N.*, **8**, 83, 1936.

‡ *M.N.*, **96**, 661, 1936; also *Ap. J.*, **87**, 568, 1938.

§ *P.A.S.P.*, **50**, 58, 1938, and *Report Mt. Wilson Obs.*, 1937–38, p. 26.

‖ *Cf.* Sanford, *Ap. J.*, **86**, 136, 1937; *Mt. Wilson Contr.*, No. 573. Also Oort, *Annales d'Astrophysique*, **1**, 79, 1938.

has, I believe, first been suggested by Beals ; * it has been worked out in considerable detail by O. C. Wilson and Merrill.† The dimensions of the individual clouds may be of the order of 200 parsecs, but the evidence on this point is somewhat conflicting. No explanation has yet been offered for how the individual motions of these clouds could be maintained, notwithstanding the circumstance that they must be continually penetrating and dissolving into each other.

Internal Motions in Clusters.—From data derived from intercomparison of, on the average, 39 pairs of plates taken with Carte du Ciel instruments, Hertzsprung ‡ has succeeded in finding some evidence of internal motions among members of the Pleiades between $8^m.3$ and $11^m.6$ pg. Titus § has recently published results of still considerably higher accuracy for the brighter Pleiades. He finds a mean square internal motion of $\pm 0''.00079$ per annum in one co-ordinate (the average mean error of his motions is $\pm 0''.00046$). Assuming a parallax of $0''.011$ the mean square velocity in one component is found to be ± 0.34 km./sec., and the total mass is estimated from this as 260 solar masses, of which approximately 200 can be accounted for by known stars in the cluster.

Schilt and Titus ‖ have likewise derived internal motions in Praesepe, for which van de Kamp ¶ had previously indicated the existence of such motions. In this case again, the results derived at the Rutherfurd Observatory, with the aid of plates taken by Rutherfurd as early as 1870, are of an unrivalled accuracy. The true mean square motion is found to be $\pm 0''.00080$ or 0.53 km./sec. in each co-ordinate.

These are the first instances in which internal motions have been found in clusters. It is much to be hoped that it will be possible to add to this knowledge by spectroscopic measures of the presumably very much larger internal velocities in globular clusters, as these data, and the masses which might be derived from them, would evidently be of the greatest value in the study of the dynamics of these objects.

Mean Parallaxes of Faint Stars.—In addition to contributing to the knowledge of the velocity distribution at large distances, the great material of motions of faint stars has been of importance for the determination of the mean parallaxes of these distant stars. Van de Kamp and Vyssotsky ** on the one hand have mainly utilized the v-components for determining secular parallaxes. As their fields were centred on bright Boss stars, the brightness of which had been reduced by a rotating sector, the mean motions of the faint stars could be directly referred to the system of Boss's Catalogue. The Radcliffe material, on account of its small and well-determined accidental errors, lends itself extremely well to a determination of mean parallaxes

* *M.N.*, **96**, 661, 1936; also *Ap. J.*, **87**, 568, 1938.
† *Ap. J.*, **86**, 44, 1937; *Mt. Wilson Contr.*, No. 570.
‡ *B.A.N.*, **7**, 187, 1934.
§ *A.J.*, **47**, 25, 1938.
‖ *A.J.*, **46**, 197, 1938.
¶ *Ap. J.*, **81**, 297, 1935.
** *Publ. McCormick Obs.*, **7**, 1937.

from the dispersion of the proper motions; * all uncertainty arising from eventual systematic errors remaining in the fundamental motions is then avoided. An attempt has been made to determine also the distribution of the stars in space from the distribution of proper motions, but a still higher accuracy of the individual motions will be required for making much progress in this direction.

For details concerning this subject reference may be made to the articles mentioned.

Proper motions of bright stars have played an important part in deriving the distribution of their distances and absolute magnitudes. This subject, on which extensive investigations have been made by Strömberg, Gratton and several others, has, however, been considered to lie outside the domain which the present note was intended to cover.

Constant of Precession.—New determinations of the constant of precession and the constant B of galactic rotation have been made by Plaskett and Pearce, van de Kamp and Vyssotsky, Oort, and Raymond and Wilson. For the results the reader may be referred to the study by Wilson and Raymond,† which is the most recent one. All these investigations from proper motions indicate a correction of about $+0''{\cdot}010$ per annum to Newcomb's constant of precession and about $+0''{\cdot}011$ for the correction needed by the proper motions in right-ascension based on Newcomb's equinox. These corrections have not, however, been used in the new fundamental catalogues. Recent results for the constant B of galactic rotation obtained in these same investigations are fairly accordant, and indicate a mean value of approximately $-0''{\cdot}0027$.

III. *Dynamics of Stellar Systems*

On the theoretical side attention has been given mainly to the study of the spiral structure of extra-galactic nebulæ, while in our own system the deviation of the vertex has been a main incentive to further researches. There are, of course, several other observational phenomena which have not been satisfactorily explained, such as the fact that the system of globular clusters does not partake in the rotation of the galactic system, that massive objects like long-period and RR Lyræ variables show so large a dispersion in their velocities, and that a number of O-type stars show peculiar radial velocities between 40 and 70 km./sec. which, if real, must be almost exactly parallel to the galactic plane, etc. Though references have been made to the first-mentioned problems, *e.g.* by Strömberg ‡ and by Lindblad, § their theories, which tie up these questions with the birth of the galactic system, are of necessity vague and do not yet seem to permit much further progress.

* van Hoof, *B.A.N.*, **8**, 67, 1936; Oort, *B.A.N.*, **8**, 75, 1936.

† *A.J.*, **47**, 56, 1938.

‡ *Ap. J.*, **79**, 460 and **80**, 327, 1934; *Mt. Wilson Contr.*, Nos. 492 and 503. See also a criticism by Gustafson and Nordström, *Zs. f. Ap.*, **10**, 228, 1935, and the answer by Strömberg, *ibidem*, p. 234.

§ *M.N.*, **94**, 231, 1934.

The Galactic System.—In a rotating system in strict dynamical equilibrium the distribution of peculiar velocities at each point should show rotational symmetry around an axis coinciding with the velocity of rotation. In case of small peculiar motions the major axis of the section of the velocity-ellipsoid with the galactic plane should point to the centre of the system, and this axis should be equal to the axis perpendicular to the galactic plane. Neither of these conditions is fulfilled in the galactic system. The axis perpendicular to the galactic plane is considerably smaller than the major axis in the plane, the ratio between the two varying with the type of stars ; and there is a considerable deviation between the galactic major axis and the direction to the centre. There appears to be no reason to worry much over the first-mentioned difference. Various authors have pointed out that, if the actual conditions in a very flat system like our own are examined more closely, it appears that in such a system an inequality between the two axes referred to is entirely compatible with the condition of approximate dynamical equilibrium.* Chandrasekhar has recently worked out this problem in some detail.†

The outstanding problem is the explanation of the deviation between the longitude of the principal vertex and that of the centre of the galactic system. While at first there seemed to be the possibility that the deviation might be only a local effect, the fact that almost all investigations of faint stars, even up to average distances of 1500 parsecs, showed a similar deviation made it evident that the deviation is a large-scale phenomenon. On the other hand it is well to remember that not all objects show the phenomenon in the same measure : the fainter dwarfs, the stars at high galactic latitude, and in general the objects of high velocity appear to give an approximately normal position for the vertex.

The observed deviation of the vertex-line proves that either the conditions in the galactic system differ considerably from that of dynamical equilibrium, or that there are large-scale deviations from rotational symmetry.

Various attempts have been made to gain an insight into the significance of the deviation. It is, of course, quite possible to construct a dynamical picture of the galactic system in which the vertex-deviation is represented, but the physical side of the problem, viz. finding a connection between this phenomenon and other data, and gaining an insight into its causes, proved to be considerably more difficult, and I think it cannot yet be said that an altogether satisfying explanation has been found. The analogy with spiral nebulæ and the appearance of the K-term in the radial velocities of bright B-stars have led some investigators to examine the properties of an expanding stellar system. It is easy to see that in an expanding system the direction of the centre as derived from the effects of differential motion will not coincide with that of the true centre, and that also other deviations from the steady-state conditions will arise. A discussion of the effects of such an expansion upon the rotation terms has been given in articles by Pilowski, Ogrodnikoff and Milne already referred to, while a similar generalization applicable to the distribution of peculiar motions, and thus

* See for instance Lindblad, *M.N.*, **96**, 71, 1935. † *M.N.*, **98**, 710, 1938.

also to our present problem, has been discussed by Shiveshwarkar.* It is difficult, however, to identify the models discussed with the galactic system, the principal objection being that, apart from the expansion shown by the bright B-stars (which is most likely due to slight group motions), the radial velocity observations, even of very distant stars, show no evidence of the existence of an expansion.

Recently, attempts in a somewhat different direction have been made by Lindblad,† which it may be of interest to examine in some detail, in connection with the possible existence of a spiral-like structure in the galactic system. Lindblad remarks that the process of condensation of gaseous and meteoric material into stars which probably takes place in a stellar system may give rise to the development of regions of instability, surrounding the much flattened inner parts of the system, so that stars moving in circular orbits near the outer edge of the flattened core will, by a slight disturbance, start off in spiral-like orbits lying outside the original core. The region where circular motions are unstable extends from the edge of the core to a certain distance R_1. The orbits corresponding to the disturbed circular motions in the unstable region may, however, extend to considerable distances beyond R_1, say to a maximum distance R_2, after reaching which they would gradually return to the edge of the core.

Lindblad has made the original suggestion that such a region of unstable circular motions might exist in the galactic system somewhat inside our distance from the centre, and that the Sun would be situated between R_1 and R_2, *i.e.* in a region where circular motions are stable, but which is traversed by the asymptotic orbits starting from the edge of the strongly flattened core. It would then be not unreasonable to suppose that, in addition to stars moving more or less at random, we should observe more or less parallel streams composed of stars emanating from the edge of the central core. There would be an in- and out-going stream of such stars, which would probably come from widely different points on the circumference of the core, so that it would be plausible to suppose that the two streams might have somewhat different moments of momentum and energies, thus causing a deviation of the vertex-line. In order that these streams, which would be composed of stars with more or less equal motions, be effective, they should comprise a considerable fraction, say half, of the stars in our neighbourhood. Lindblad notes that the moving clusters in Taurus and Ursa Major might be considered as the cores of such streams ; it should, however, be remarked that the stars as a whole show little evidence of their belonging to two distinct streams of this kind. It is also to be noted that, in any simple model of the galactic system, the existence of an inner

* *M.N.*, **95**, 655, 1935. See also *M.N.*, **96**, 749, 1936. See also Heckmann, *M.N.*, **96**, 67, and Lindblad, *M.N.*, **96**, 71, 1935.

† *Stockholms Obs. Ann.*, **12**, No. 4, 1936 ; also an article in the *Östen Bergstrand Festskrift*, 1938. Both papers contain a review of Lindblad's recent work on the dynamics of stellar systems in general, together with extensive references to the recent work of others. I may refer the reader to the first-mentioned article for a great many details which cannot be treated in the present note.

region of unstable motions, from which the "asymptotic" orbits extend beyond the Sun, would appear to be accompanied, in our neighbourhood, by a fairly strong decrease of the circular velocity with R, which it seems difficult to reconcile with the very slight decrease, of about ·005 km./sec. parsec, actually observed.* It may be, however, as Lindblad has remarked, that the streams are but remnants of orbits originated from former unstable regions which at present are no longer important.

Perhaps the most plausible interpretation of the vertex-deviation might be obtained by dropping the idea that the galactic system has rotational symmetry. Recent investigation of the distribution of density in the galactic system has indicated large-scale unevenness in the distribution of stars. An intimate connection must necessarily exist between the characteristics of the distribution of density in the surrounding of the Sun and the characteristics of the distribution of peculiar motions (while, at the same time, the systematic motions of B-type stars, etc., need not be disturbed). From this point of view it is hardly surprising to find that the vertex deviates somewhat from the position it would have if the density distribution were entirely regular. The density data are, however, by no means sufficiently accurate to establish a correspondence with the observed vertex-deviation.

The occurrence in our neighbourhood of extensive local groups of early-type stars, which groups are of such loose structure that it seems unlikely that they could be held together against the disturbing influence of the galactic gravitational field, proves that the galactic system is in some respects still far from a steady state. From the known effects of differential rotation we can estimate that an agglomeration of the kind of the southern group of B-stars could not have existed in something like its present form during much more than 10^8 years, or half of a revolution of the galactic system. It is fairly certain that the age of the galactic system is much higher and we would have to conclude, therefore, that either the assumption that the wide B-star groups are not held together by gravitation is wrong or that these stars are of much more recent formation than the majority of the stars in the galactic system.

The problem of the stability of groups of stars and of open clusters has been fully discussed by Bok,† while more recently a mathematical treatment of the subject has been given by Mineur.‡ Bok concludes that groups become unstable if their density falls below about one-tenth of the mass of the Sun per cubic parsec; clusters of lower density are rapidly disrupted by the general gravitational field of the galactic system. Those of higher density will at first disintegrate much more slowly by the effect of encounters, as has already been pointed out in classical papers by

* Calculations based on simple schematic models give values of the order of ·015 to ·018 km./sec. parsec for this quantity. Lindblad now informs me that he has made calculations for a more complicated model, in which the core contains a ring-shaped formation; this model would give a better agreement with the observations.

† *H.C.*, No. 384, 1934.

‡ *Comptes Rendus*, May 31, 1937, p. 1620.

Jeans and Eddington. From the conditions of existing clusters Bok estimates that 2×10^{10} years represents a reasonable upper limit to the age of the galaxy.

Extra-galactic Nebulæ.—The deviations from a smooth state indicated in the preceding are by no means peculiar to the galactic system, but are found in the majority of extra-galactic systems; they are usually exhibited on a very large scale in the spiral structure of these systems.

It is not improbable that an insight into the cause and the dynamics of the spiral structure, which is probably shown by all systems of a flattening comparable to that of the galactic system, would at the same time enable us to a much better understanding of the dynamics of our own system, and *vice versa*. But at present this does not yet seem to be the case. Though a great deal of work has been done on the subject of spiral structure and some notable progress has been made (in recent years especially by Lindblad, Vogt, Lambrecht, Bucerius), the problem is of such complexity that it has not been possible, except in a few special cases, to deal with it in a quantitative manner. Apart from the intricacy of the problem and the circumstance that we know nothing of the initial conditions, there is the difficulty that except for the shape of the arms there are very few observational data to build on. The measures, recently made by Humason* on Mount Wilson and by Horace W. Babcock† at the Lick Observatory, of the rotational velocity in various regions of a few elliptical and spiral nebulæ are, therefore, of the greatest importance.

The lack of quantitative knowledge about the dynamics of spiral structure may typically be illustrated by the fact that it has not been possible to obtain agreement about the sense of the rotation of spiral nebulæ with respect to the direction in which the arms are wound. Nevertheless, the investigations carried out must certainly be considered to be of great value in preparing the way for a successful attack. An adequate discussion of the progress already made is, however, outside the scope of the present note.

J. H. OORT.

* *Report Mt. Wilson Obs.*, 1936–37, p. 31.
† *P.A.S.P.*, 50, 174, 1938.

THE CONTINUOUS ATOMIC ABSORPTION OF LIGHT

I. *Introduction and Theory*

The continuous absorption of light or, more exactly, the atomic coefficient of continuous absorption, α_ν, is of considerable importance in modern astrophysical theories of stellar structure and stellar atmospheres.* It is obvious in this connection that the amount of absorption not only determines the state of equilibrium but also the final spectrum shown by a star. The coefficient, α_ν, also enters theories of nebular luminosity and other problems of astronomical interest.

In 1923 H. A. Kramers † developed a law governing the continuous absorption of X-rays, and this law has been used, in many cases erroneously, to evaluate the optical absorption in astrophysical problems. Kramers, by using the methods of classical electrodynamics, assuming the Bohr model of the atom, and introducing the Correspondence Principle, found the following formula for the atomic coefficient, *i.e.* the percentage absorption per atom in a column of 1 cm.^{2} cross-section at any wave-length, λ, shorter than the wave-length, λ_n, of the n^{th} absorption limit of an element of atomic number, Z:

$$\alpha_\nu(n) = \frac{64\pi^4 e^{10} m}{3\sqrt{3}c^4h^6} g \frac{Z^4\lambda^3}{a_n n^3}, \qquad (1)$$

where

$$\frac{64\pi^4 e^{10} m}{3\sqrt{3}c^4h^6} = 0{\cdot}0104,$$

g is a factor near unity, and $a_n = n(n+1)$ is the statistical weight of the n^{th} state. Such absorption, of course, results in the ejection from the atom of an electron with a certain velocity, v, as given by the photo-electric equation:

$$\tfrac{1}{2}mv^2 = \frac{hc}{\lambda} - \frac{hc}{\lambda_n}. \qquad (2)$$

(Planck's constant, $h = 6{\cdot}55 \times 10^{-27}$ erg sec. and $c = 3 \times 10^{10}$ cm./sec.).

In the derivation, Kramers considered the nucleus and the disturbed electron as isolated. He treated what we shall call the "*Hydrogenic*" model—a single electron moving round a nucleus of charge $+Ze$. In the case of X-ray absorption, neglecting the other electrons in the atom seems to be justifiable; at least the agreement between prediction and the experimental measurements is fairly accurate.‡ However, over large ranges of Z and λ the agreement is not exact. Thus Jönssen § finds that, to a first

* Eddington: *M.N.*, 84, 104, 1924; *Internal Constitution of the Stars*, chap. ix. Bierman, *Gött. Nach.*, Nos. 45, 49, 1933. Pannekoek, *Pub. Ast. Inst. Amsterdam*, No. 4, 1935. Unsöld, *Zs. f. Ap.*, 8, 32, 225, 1934. Strömgren, *Zs. f. Ap.*, 4, 118, 1932; 7, 222, 1933.

While this paper has been in preparation, a book has appeared by Finkelnburg, *Kontinuerliche Spectren* (J. Springer, 1938), which summarizes some of this material (his Chapters III and IV).

† Kramers, *Phil. Mag.*, 46, 837, 1923.

‡ Richtmeyer, *Phys. Rev.*, 18, 13, 1921. Compton and Allison, *X-rays in Theory and Experiment*, 1935.

§ Jönssen, *Thesis, Uppsala*, 1928, or Compton and Allison, *loc. cit.*

approximation, $a_\nu n^4/Z$ varies with $(Z\lambda)^3$ for all elements of low Z and for wave-lengths sufficiently small. This means that $a_\nu \propto n^{-4}$, whereas

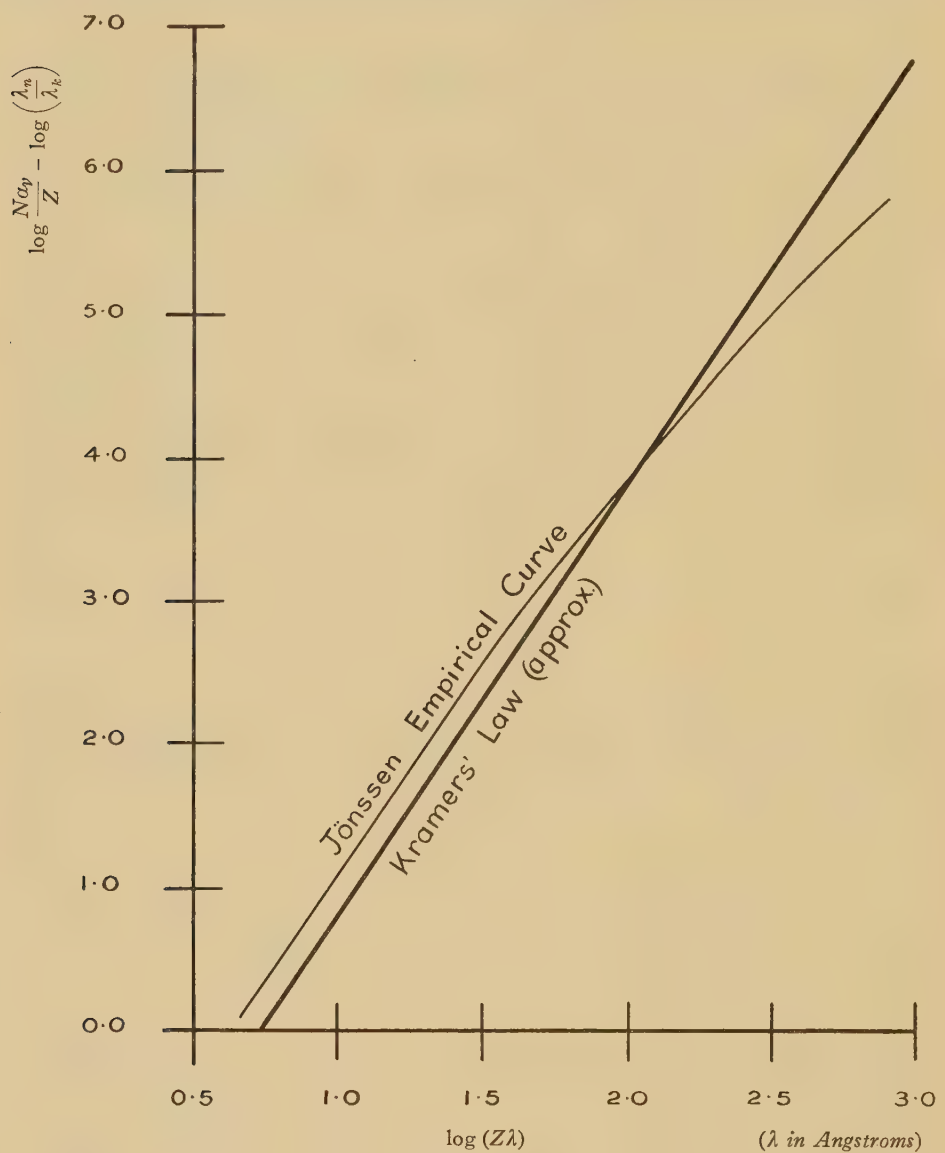


FIG. 1.—*X-ray Absorption.*

Kramers' Law, equation (1), predicts $a_\nu \propto 1/n^4(n+1)$. Fig. 1 shows Jönssen's "Universal Absorption Curve," which represents within 5 per cent. error the experimentally measured X-ray absorption coefficient for different elements. For low $Z\lambda$ the observed a_ν varies as predicted, although its absolute value is 1·8 times too large. For larger $Z\lambda$, a_ν is some six times smaller than predicted and varies as $Z^3\lambda^2$.

It is evident, therefore, that Kramers' Law of X-ray absorption breaks down for heavy atoms and certainly for wave-lengths greater than 1 A. In addition, certain unpredicted fluctuations in a_ν have been measured near X-ray absorption limits.* This "fine structure," which amounts to over 10 per cent. deviation from a smooth λ^3 curve of a_ν, has been shown † to be due to the fixed positions of atoms in crystals or molecules. It extends as far as 100 electron-volts from the absorption limits. Analagous effects are to be expected over a large portion of the spectrum in the optical absorption by closely packed atoms, or atoms combined in molecules.

The theoretical analysis leading to Kramers' Law can obviously be applied to the optical absorption of the simple hydrogen atom. Recently several wave-mechanicians ‡ have arrived independently at the same or equivalent expressions for the absorption by the hydrogen atom, each derived from the Schrödinger wave equation. Apparently this consensus of opinion overwhelmed astrophysicists, who immediately used Kramers' formula (equation (1)) to calculate the optical absorption for alkali atoms and for other atoms even less hydrogen-like. Strictly the equation (1) should only be expected to apply to H, He^+, Li^{++} and further hydrogenic ions consisting of one electron and a tightly packed nucleus. As an approximation it might conceivably hold true for the hydrogen-like alkali atoms *Li*, *Na*, *K*, *Rb* and *Cs*, where one electron revolves about a loose core of nucleus and electrons. § But this latter expectation proves not to hold true on more rigorous analysis. Thus Trumpy ‖ and Miss Phillips ¶ calculated a_ν from the Schrödinger wave equation, using the Hartree mathematically self-consistent fields for *Li*, *Na* and *K*. Their curves of a_ν above the principal series limits of these elements differ widely from Kramers' Law, (1). Not only does a_ν decrease more rapidly than λ^3 (except for *Li*) (*cf.* fig. 2), but the predicted absolute value for *Na* and *K* is some 100 times smaller by this calculation than Kramers' formula would indicate. Specific calculations ** of a_ν for helium also yield results differing widely from Kramers' formula, and the continuous optical absorption by other elements varies with λ in a much more complicated way. This discussion, therefore, will be limited to the "hydrogen-like" elements, for which Kramers' formula has previously been assumed to hold true.

Before turning to experimental evidence it is well to point out an important connection between a_ν and other observable atomic properties. This is the Milne relation †† between absorption and re-emission of light; *i.e.* between ionization and the probability of recombination of ion and electron. From thermodynamical considerations (in particular the detailed

* Hanawalt, *Phys. Rev.*, **37**, 715, 1931; Coster and Klamer, *Physica*, **1**, 889, 1934.

† Kronig, *Zs. f. Phys.*, **70**, 317, 1931; **75**, 191, 468, 1932. Hartree, Kronig, Petersen, *Physica*, **1**, 895, 1934.

‡ Sugiura, *Jour. Phys. Rad.*, **8**, 113, 1927; Gaunt, *Phil. Trans.*, **229A**, 163, 1929; Menzel and Pekeris, *M.N.*, **96**, 77, 1935; Maue, *Ann. der Phys.*, **13**, 161, 1932.

§ In this case, of course, the charge on the loose core is one electronic unit; $Z=1$.

‖ Trumpy, *Zs. f. Phys.*, **71**, 720, 1931.

¶ Miss Phillips, *Phys. Rev.*, **39**, 905, 1932.

** Wheeler, *Phys. Rev.*, **43**, 258, 1933.

†† Milne, *Phil. Mag.*, **47**, 209, 1924.

balancing of reversible processes) of ions, atoms and radiation in an enclosure, Milne showed * that the two atomic constants, absorption coefficient a_ν and

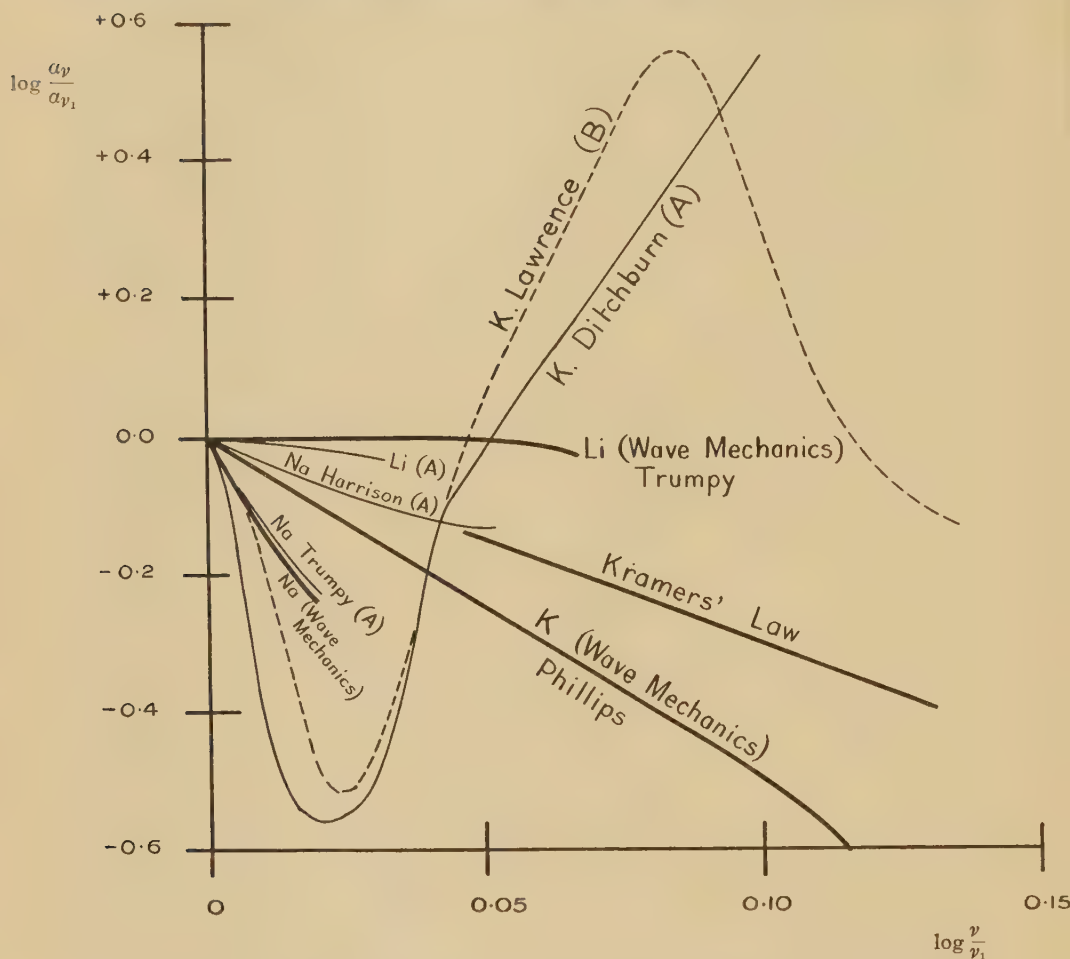


FIG. 2.—*Absorption by the alkali vapours Li, Na and K. The theoretical predictions (heavy lines) are compared to values measured by Method A (full thin lines) and Method B (dashed thin lines).*

References to the authors credited on each curve will be found in the text. For Becker's empirical law see fig. 3.

the probability of capture † $F_n(v)$, are connected by the equation

$$4\pi(h\nu)^2 a_\nu(n) = v^2 F_n(v)(2\pi mc)^2 \frac{a}{a_n}, \qquad (3)$$

* More rigorously and exactly than Kramers, *loc. cit.*, and Stobbe, *Ann. der Phys.*, **7**, 661, 1930.

† $F_n(v)$ is analytically defined by equation (8) below. a is the statistical weight of the ionized state.

where frequency $\nu \left(\nu = \frac{c}{\lambda}\right)$ and velocity v are related by the photo-electric equation (2), and the physical constants are represented by usual symbols. This equation connecting absorption or ionization with emission or recombination is fundamental in the study of these atomic processes.

Knowing the capture probability of certain atoms from canal-ray experiments, therefore, Becker * arrived at a semi-empirical law of absorption :

$$\alpha_\nu(1) = \frac{\text{constant}}{(\nu - \nu_1)\nu^2}, \qquad (4)$$

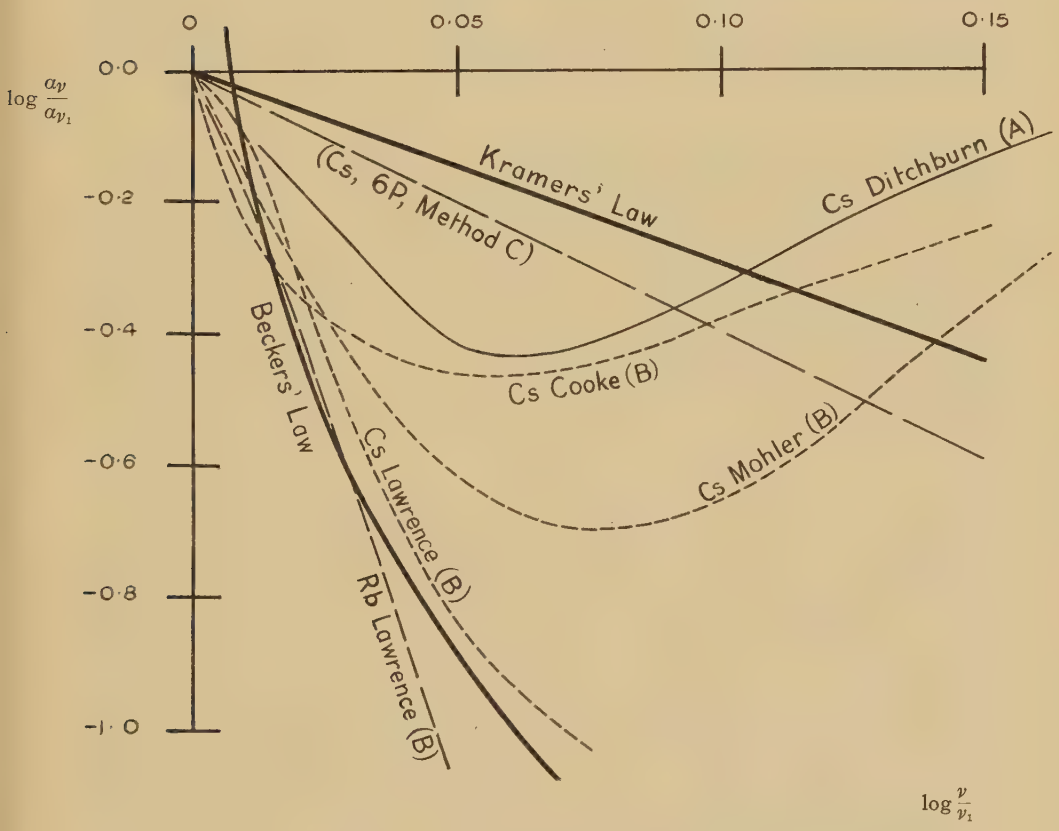


FIG. 3.—*Absorption by the alkali vapours Rb and Cs. Authors and methods are indicated as in fig. 2. The absorption coefficient for excited Cs as measured by Mohler using Method C is included as a thin long-dashed line.*

where ν_1 is the frequency of the principal series limit. In figs. 2 and 3 (where the theoretical predictions are shown by heavy lines) it is seen that Becker's law differs from the others, and aside from the discontinuity at the series limit, ν_1, that it closely represents the continuous absorption of certain alkali vapours.

* Becker, *Zs. f. Phys.*, **18**, 325, 1923.

II. *Laboratory Measurements*

It is generally agreed that, within experimental error, the ultimate source of information as to the absorption coefficient lies with laboratory measurements. Unfortunately these are difficult to make directly, and thus some of the values have been computed from indirect measures. The experimental values of α_ν can therefore be divided into three groups :

(A) those measured directly,
(B) those derived from measurements of ionization, and
(C) those derived (by means of equation (3)) from measurements of continuous emission due to recombination.

The methods used under these three headings and the results will be discussed in order.

(A) *Direct Measurements of Absorption*

Direct measurements were initiated by R. W. Wood* in 1909, who first observed continuous absorption above the principal series limit of *Na* (at λ 2410). His method, followed by succeeding workers, consisted in filling with the vapour of one of the alkali elements a long evacuated steel tube, closed by quartz end-windows, and photographing through this tube the spectrum of a *Cd* spark or other source of continuous spectrum. A measurement is made of the difference in intensity between the beam entering and that leaving the tube. The coefficient, α_ν, is then defined † by

$$\frac{dI_\nu}{I_\nu} = \alpha_\nu N_l, \qquad (5)$$

where the intensity dI_ν is absorbed from the incident intensity, I_ν (at the frequency ν) by N_l atoms in each cm.^{2} column of the beam. $N_l = \frac{\rho N l}{A}$ if the column of vapour has density ρ and length l, N being Avagadro's number ($6{\cdot}06 \times 10^{23}$ per gm. molecule) and A the atomic weight of the element vaporized.

Wood made no quantitative measurements, but Harrison,‡ Trumpy,§ Ditchburn, || and Braddick and Ditchburn¶ have progressively increased the accuracy of the method. There are, however, four types of error inherent in these measurements due to :

(*a*) impurities in the atomic vapour,
(*b*) changes in the light source,
(*c*) selective absorption by the end-windows, and
(*d*) inaccurate photometry.

* Wood, *Phil. Mag.*, **18**, 530, 1909.

† This definition is chosen in order to compare most easily the experimental and theoretical values. The relations of other definitions to this are given by Finkelnburg (*loc. cit.*).

‡ Harrison, *Phys. Rev.*, **24**, 466, 1924.

§ Trumpy, *Zs. f. Phys.*, **47**, 804, 1928 ; **71**, 720, 1931.

|| Ditchburn, *Proc. Roy. Soc.*, **117** A, 486, 1928.

¶ Braddick and Ditchburn, *Proc. Roy. Soc.*, **143** A, 472, 1933.

It is not necessary here to examine these errors in detail. Research workers have each carefully eliminated one or more, but to estimate the final error of their results from published data is impossible. Some of the measurements are plotted (by full, thin lines) in figs. 2 and 3, where the partial agreement between the results obtained by different physicists using different methods (on the same element) indicates the accuracy.

The graphs in figs. 2 and 3 show relative values of a_ν ; *i.e.* a_ν/a_{ν_1}, where ν_1 is the frequency of the principal series limit. In plotting log a_ν/a_{ν_1} against log ν/ν_1, Kramers' Law is represented by a straight line of slope -3 passing through the origin. The absolute values of a_{ν_1}, which also result from these measurements but which are of low accuracy * due to the error in measuring N_l, are given in Table I where they may be compared with other experimental and the theoretical values.

TABLE I

Absolute Values of the Atomic Absorption Coefficient, a_{ν_n} (in cm.^{2}), at the Series Limits of the Alkali Elements

Element, Series, and Effective n	Experimental			Theoretical	
	Method A	Method B	Method C	Kramers' Formula (Eff. $Z=1$)	Wave Mechanics
Li Prin., 1·6	...	...	...	$0{\cdot}7 \times 10^{-17}$	$0{\cdot}37 \times 10^{-17}$ (Trumpy)
Na Prin., 1·6	10^{-18} (Harrison)	...	...	$0{\cdot}8 \times 10^{-17}$	$3{\cdot}1 \times 10^{-19}$ (Trumpy)
K Prin., 1·8	10^{-19} (Ditchburn)	...	...	$0{\cdot}9 \times 10^{-17}$	$0{\cdot}19 \times 10^{-19}$ (Phillips)
Rb Prin., 1·8	...	$1{\cdot}1 \times 10^{-19}$ (M + B)	...	$0{\cdot}9 \times 10^{-17}$	...
Cs Prin., 1·9	4×10^{-19} (M + B) $4{\cdot}5 \times 10^{-19}$ (B + D)	6×10^{-19} (Cooke) $2{\cdot}3 \times 10^{-19}$ (M + B)	...	$0{\cdot}9 \times 10^{-17}$	...
Cs S, D, 2·3	...	...	$3{\cdot}6 \times 10^{-17}$ (Mohler)	$2{\cdot}5 \times 10^{-17}$	...
Cs F, 2·6	...	...	3×10^{-17} (Mohler)	$3{\cdot}7 \times 10^{-17}$	...

The names in brackets indicate the authors credited with each value. M + B indicates Mohler and Boeckner, B + D indicates Braddick and Ditchburn. The values in the column headed "Kramers' Formula" were obtained by inserting in equation (1) the effective quantum number from column 1 for n, the series limit wave-length for λ, the experimentally found statistical weight or $n(n+1)$ for a_n and the effective $Z=1$.

* They are usually assumed to be upper limits of the true a_{ν_1}.

(B) *Measurements of Ionization*

In this method a monochromatic light beam of frequency ν passes into an atomic vapour, some ions are formed, and a coefficient, B_ν, equal to the percentage of atoms ionized per second per unit intensity of the incident beam is measured. Since each ionization withdraws $h\nu$ ergs of energy from the light beam, it is evident that

$$\frac{a_\nu I_\nu N_l}{h\nu} = B_\nu I_\nu N_l, \quad \text{or} \quad B_\nu = \frac{a_\nu}{h\nu}. \tag{6}$$

The number of ions formed per second is recorded as a small current through the vapour between two electrodes of potential difference great enough to collect all the ions and (supposedly) not great enough to cause secondary ionization. In fact, if this current, i, is measured in amperes,

$$B_\nu = \frac{iN/F}{I_\nu\left(\rho\frac{Nl}{A}\right)} \tag{7}$$

(Faraday's number, F, is 96494 coulombs per gm. molecule).

In addition to the four errors mentioned under Section (A), there are further errors inherent in this method due to:

(e) recombination of ions on the walls or electrodes of the tube,
(f) inaccurate amplification of the ion current i, and
(g) secondary ionization by high velocity photo-electrons.

Here, again, much has been done in eliminating experimental error. Early workers * restricted the atomic vapour to a narrow beam avoiding walls and electrodes, but had difficulty in amplifying i for accurate measurement. Foote and Mohler † introduced an important innovation in using the neutralization of space charge by the positive photo-ions around a hot filament (the negative electrode of their apparatus) to amplify i by a large but unknown factor. A box-shaped anode surrounding the illuminated vapour and filament prevented recombination of ions on the walls of the tube.

This apparatus was further improved by Lawrence and Edlefsen ‡ who balanced two such space-charge tubes, symmetrically built, in order to eliminate variations in the amplification. The vapour in only one of the tubes was illuminated and the difference in ion current was then an accurate measure of the photo-ionization, unaffected by errors of the types (e) and (f).

In figs. 2 and 3 the relative values resulting from Method B § are plotted by dashed lines. The agreement with direct absorption measurements is fairly good, while the disagreement with theoretical predictions is very

* Williamson, *Phys. Rev.*, **21**, 107, 1923 ; Lawrence, *Phil. Mag.*, **50**, 345, 1925.

† Foote and Mohler, *Phys. Rev.*, **26**, 195, 1925 ; **27**, 37, 1926. Mohler and Boeckner, *Bur. Stand. J. Res.*, **3**, 303, 1929.

‡ Lawrence and Edlefsen, *Phys. Rev.*, **34**, 233, 1929 ; **34**, 1056, 1930.

§ Other ionization measurements were made by Little, *Phys. Rev.*, **30**, 109, 963, 1927: Cooke, *Phys., Rev.*, **38**, 1351, 1931.

marked. Becker's semi-empirical law fits the observed α_ν for *Cs* and *Rb* (as measured by Lawrence and Edlefsen) quite well over the small range of 0·5 volts (to approx. $\log \nu/\nu_1 = 0{\cdot}07$), but this may well be a coincidence since the capture probability data used by Becker were measured for much higher energies.

Perhaps the most outstanding difference between theoretical prediction and observation is, for the heavier alkalis, the marked rise in α_ν toward shorter wave-lengths after a minimum at about 0·5 electron-volts energy from the series limit. A plausible and much-used explanation of this disagreement is that unstable diatonic molecules, K_2, Cs_2, etc., are present in the vapour and are dissociated, *e.g.*:

$$K_2 + h\nu \rightarrow K + K^+ + (\tfrac{1}{2}mv^2)_{\text{electron}}.$$

However, the low dissociation energy (0·5 e.v. or so) of such molecules, necessarily assumed in order to explain the effect, results in an almost negligible proportion of such molecules * in the atomic vapour at the pressures (near 1 mm. *Hg*) and temperatures (greater than 500° *K*) used in the experiments.

Another effect of molecules on the optical absorption might be analogous to the Kronig † fine structure in X-ray absorption limits, but since no correlation exists between the experimentally observed minimum of α_ν and either the temperature or the pressure of the vapour (which would affect molecular concentration), this explanation must also be discounted. Again, errors of the type *f* (secondary ionization by photo-electrons) might produce an apparent increase in B_ν at short wave-lengths, ‡ and indeed some correlation does exist between the potential differences (from 1 to 10 volts) used across the electrodes and the observed minimum point in α_ν measured by Method B. However, such an explanation is obviously inadequate; it does not explain the rise in α_ν in the direct absorption measurements nor the difference between the position of absorption minima in *K*, *Rb* (if any) and *Cs*.

The absolute measurements of ionization § yield values of α_ν which, because of the several types of error involved, are neither upper nor lower limits to the true value. They agree fairly well, however, with the results of Method A, as may be seen in Table I.

All in all, it must be concluded from the results of Methods A and B that α_ν for the ground states of the alkalies cannot be computed from the Kramers' formula. The more rigorous calculations of wave mechanicians predict the absolute value of α_{ν_1} in Table I fairly accurately but fail in regard to the variation with λ as shown by figs. 2 and 3.

* Braddick and Ditchburn, *loc. cit.*; Mohler and Boeckner, *Bur. Stand. J. Res.*, 5, 51, 1930; Miss Phillips, *loc. cit.*

† Kronig, *loc. cit.*

‡ When the energy of the photo-electron plus the energy it can acquire in the electric field between the electrodes is greater than the ionization potential, secondary ionization by electron collision may take place.

§ Mohler and Boeckner, *loc. cit.*, 1929; Cooke, *loc. cit.*; Little, *loc. cit.*; (in error: *cf.* Cooke).

For a long time it was thought that absorption between the higher series lines on the red side of the series limit (measured by several workers *) was another disagreement with theory, but this can be accounted for by pressure effects,† broadened lines,‡ and poor spectrographic resolving power.

(C) *Measurements of Recombination*

In a mixture of ions and electrons, the number of recombinations involving an electron with velocity near v and resulting in an atom in the n^{th} quantum level will be

$$N_n(v)dv = 2\pi n_2 v \phi(v) F_n(v) dv \tag{8}$$

per sec. per cm.^{3}, where n_2 is the number of ions per cm.^{3} and $\phi(v)dv$ is the number of electrons per cm.^{3} with velocities between v and $v+dv$. Each of these captures results in the emission of one quantum of light with a wave-length determined by the photo-electric equation (2). Using Milne's relation (3), we find the intensity in the continuous emission to be §

$$I_\nu d\nu = \frac{8\pi^2(h\nu)^3 a_\nu}{(2\pi mc)^2} \frac{a_n}{a} n_2 \frac{\phi(v)}{v} dv, \tag{9}$$

and therefore a_ν can be derived from measurements of I_ν if $\phi(v)$, the electron velocity distribution, is known. Langmuir and others || have shown that in most electrical discharges through low-pressure vapour, $\phi(v)$ is very closely Maxwellian, *i.e.*

$$\phi(v)dv = 4\pi y \left(\frac{m}{2\pi k T_\epsilon}\right)^{\frac{3}{2}} e^{-\frac{1}{2}\frac{mv^2}{kT_\epsilon}} v^2 dv, \tag{10}$$

where T_ϵ is a parameter called the "electron temperature" and y is the number of electrons per cm.^{3}.

In 1928 Mohler ¶ measured spectral intensities due to recombination in the emission from a specially designed *Cs*-vapour discharge tube. An advantage of the Method C is apparent in the fact that he was able to measure continuous emission above several series limits, thus determining relative values of $a_\nu(n)$ for several values of n. Strikingly enough, the recombination on the ground state, as measured by the emission above the principal series limit, was found to be much smaller than that on higher quantum levels of *Cs*. In addition, the resulting variation of a_ν with λ for the higher states (plotted in fig. 3 by long dashed lines) is neither that predicted by Kramers' formula nor the same as measured by Methods A and B for the ground state.

* Harrison, *loc. cit.*; Ditchburn, *loc. cit.*

† Robertson and Dewey, *Phys. Rev.*, **31**, 973, 1928; Kudar, *Zs. f. Phys.*, **57**, 705, 1929.

‡ Pannekoek, *M.N.*, **98**, 694, 1938.

§ A formula due to Cillié: *M.N.*, **92**, 820, 1932. His definition of a_ν differs slightly from that adopted here.

|| Langmuir and Compton, *Rev. Mod. Phys.*, **2**, 123, 1930; **3**, 191, 1931.

¶ Mohler, *Phys. Rev.*, **31**, 187, 1928.

Mohler * later measured $\phi(v)dv$ by the probe method and, after correcting for a systematic error, he derived the absolute values of a_ν for the 6P and 5D states of *Cs*. These absolute values, as Table I shows, are very close to those predicted by Kramers' formula (using the "effective quantum number" for n). This evidence indicates that a non-hydrogenic atom, as might well be expected, becomes more and more hydrogenic in its absorption properties as it is excited to higher and higher quantum levels.

Measurements of the Balmer and Paschen continuous emission in a hydrogen discharge tube by Chalonge † and Page ‡ indicate that the ratio of $a_\nu(2)$ to $a_\nu(3)$ agrees with that predicted by Kramers' Law (*i.e.* $a_\nu(3)/a_\nu(2) = 0{\cdot}06$ at the series limits). No probe measurements of $\phi(v)$ were made in these experiments, but the form of I_ν indicates that a_ν varies as λ^3 if $\phi(v)$ can be assumed Maxwellian. Kramers' Law (equation 3) thus seems experimentally to be proved valid for hydrogen, at any rate.

Other observations of recombination in the afterglow of discharges have only been qualitative and have merely indicated that $F_n(v)$ decreases with increasing v, for *Hg* § and Argon. ||

III. *Summary and Conclusion*

The material discussed in this note forms only a small portion of an extensive study of the continuous absorption of light. The optical absorption by molecules, for instance, and even by the atoms not mentioned above, is far more complicated in its quantitative aspects.¶

The experimental findings in general are marked by considerable disagreement, both internally and as compared with theoretical predictions. The simple Kramers absorption formula which could theoretically only be expected to hold for hydrogen, hydrogenic ions, and the absorption of short X-rays, does in fact apply only in these cases—at least as far as yet known from experiment. Other formulæ based on wave mechanics and applicable only to the ground states of single elements in the alkali group succeed in predicting the order of magnitude of the observed absorption, but seem to fail with regard to the variation of absorption with decreasing wave-length.

Experiments also indicate, quite in order with general atomic theory, that when an atom is excited to a higher quantum level its absorption becomes more hydrogenic and approaches agreement with Kramers' formula.

Undoubtedly the many observational errors and unwanted extraneous effects have introduced complications into the results. Such a complication is the apparent continuous absorption on the long-wave side of the series limit : an effect which has been satisfactorily explained.

* Mohler and Boeckner, *Bur. Stand. J. Res.*, **2**, 489, 1929 ; Mohler, *Nature*, **142**, 1160, 1938.

† Chalonge, *Ann. de Phys.*, **1**, 123, 1934.

‡ Page, *Nature*, **142**, 615, 1938.

§ Lord Rayleigh, *Proc. Roy. Soc.*, **108** A, 262, 1925 ; Miss Hayner, *Zs. f. Phys.*, **35**, 365, 1926.

|| Kenty, *Phys. Rev.*, **32**, 624, 1928.

¶ Finkelnburg, *loc. cit.*

Certainly a great deal more work must be done before astrophysicists can make reliable inferences as to the general absorption by a large variety of atoms, especially in the outer layers of a star * where the radiation is mainly in optical wave-lengths. In particular, the experimental proof of Kramers' Law in its application to atomic hydrogen can profitably be repeated, since that application is in such widespread use. One astronomical proof may be possible from observations of stellar spectra before and after the star is obscured by a moving gaseous nebula or an expanding shell of gas from a nova. The physical conditions pertaining to such observations are probably simpler than any obtainable in laboratory experiments.

T. L. PAGE.

* Milne (*M.N.*, 98, 21, 1937) has shown that the "opacity" appearing in the equations of stellar equilibrium is that of the outer layers only.

SEISMOLOGICAL TABLES

The prediction that an elastic solid should be able to transmit two distinct types of bodily waves was first made by Poisson in 1829. The first is similar to the sound wave in a liquid or gas ; when it passes a particle, that particle vibrates in the direction of travel of the wave. Such a wave is called longitudinal or compressional, the latter term being used because the passage of the wave is associated with changes of volume. The second type can occur only in a solid ; when it passes a particle, the particle is displaced at right angles to the direction of travel of the wave. It is often called transverse or distorsional. The velocities α and β are given, in terms of the elastic properties and density of the material, by the equations

$$\alpha^2 = (\lambda + 2\mu)/\rho \; ; \quad \beta^2 = \mu/\rho,$$

where ρ is the density, μ the rigidity and $\lambda + \frac{2}{3}\mu$ the bulk-modulus or the reciprocal of the compressibility. For the type of solid considered by Poisson, $\lambda = \mu$ and $\alpha = \beta\sqrt{3}$.

Such waves can travel freely in any direction, and may therefore be called *bodily waves*. It was first recognized by Rayleigh that there is also a type that can travel over the surface with a velocity rather less than β, the amplitude diminishing with depth and being inappreciable at depths more than a few wave-lengths. Another type of surface wave, found by observation, was explained by Love in 1911 ; it is a transverse wave that can exist in a stratified material.

Though these predictions had long been made, and though instruments for recording the arrival of earthquake waves at distant stations had existed for a long time, it was not until 1900 that the longitudinal, transverse and surface waves were first clearly separated in the records, by R. D. Oldham.* They are now generally known by the symbols *P*, *S* and *L*, introduced by Wiechert and von den Borne.† *P* stands for *primary* and *S* for *secondary*, on account of the difference of velocity ; Turner suggested that they might equally be taken to represent *push* or *shake* on account of the different characters of the movement : though *P* is as often as not a *pull*. *L* stands for *large* or *long* because the surface waves at great distances are larger and have longer periods than the bodily ones. Oldham produced provisional tables of travel times for these phases, but these were superseded by those of Zöppritz ‡ of 1907. One feature of *S* that was not much emphasized in the earlier work has recently become very important. There is only one possible direction of movement of a particle in a *P* wave travelling in a definite direction, but in an *S* wave the particle can be displaced in any

* *Phil. Trans.*, A, **194**, 135–174, 1900.
† *Gött. Nachr.*, 1904.
‡ *Gött. Nachr.*, 529–549, 1907.

direction perpendicular to the direction of travel; in other words, *S* shows polarization, *P* does not. The paths through the earth lie in planes through the centre. *S* displacements in these planes are usually denoted by *SV*, at right angles to them by *SH*. The two types of *S* travel with the same velocity, but behave differently on reflexion or refraction. *SH* can give rise to nothing but *SH*, but *SV* gives a combination of *P* and *SV*. Similarly *P* on reflexion or refraction gives a combination of *P* and *SV*. The difference here from the optical conditions is that two boundary conditions instead of one have to be satisfied at a free surface, four instead of two at an interface, since both the stress and the displacement must be continuous. (More strictly the numbers are six and three; but the treatment of *SH* is simple and can be taken separately.)

Many continental workers after Zöppritz made attempts to improve on his times, notably A. and S. Mohorovičić and B. Gutenberg. The results, however, differed appreciably, and Turner considered it advisable to use the Zöppritz times, in a modified and extrapolated form, as a basis of comparison until it was clear what changes were needed. The result was that they were used in the International Seismological Summary for earthquakes up to the end of 1929 (published in 1933). Turner,* however, published an important paper in 1926, in which he classified the residuals for 1918–22 against the Z.T. tables by distance, and obtained corrections varying with distance by about 20^s for *P* and 30^s for *S*. About the same time P. Byerly † gave a set of times based on his special study of the Montana earthquake of 1925 June 28. I compared these with the provisional corrections found by Turner, and found a very close agreement.‡ It appeared at this stage that these corrections were not likely to be far wrong. In two later papers § I extended Turner's work to the earthquakes of 1923 to March 1927, and again got similar corrections, which are embodied in my 1932 tables, published by the British Association Seismological Committee. The apparent standard errors of these times were mostly under a second, but there were grounds for mistrusting them. The corrections were simple means of the residuals (apart from a modification to take account of departure from the normal law of error) against the Z.T. times; but the epicentres and times of occurrence had been found so as to give the best possible agreement with the latter, and in different earthquakes the bulk of the observations were at different distances. Thus part of the variation of the corrections with distance would have been converted into errors of the epicentres and times of occurrence, and would not be revealed by a mere classification of the residuals. I called attention to this feature at the time (p. 337), but some critics appear to have overlooked the warning. The Z.T. times being taken as a first approximation, my 1932 ones were a second approximation, but it was necessary to complete the process before the apparent accuracy could be claimed as genuine.

* *M.N., Geophys. Suppl.*, **1**, 425–446, 1926.
† *Bull. Seism. Soc. Amer.*, **16**, 209–265, 1926.
‡ *M.N., Geophys. Suppl.*, **1**, 500–521, 1928.
§ *M.N., Geophys. Suppl.*, **2**, 329–348, 399–406, 1931.

At this stage I obtained the valuable assistance of K. E. Bullen. It was necessary to reduce afresh all the earthquakes used for P and S, determining corrected epicentres and times of occurrence so as to give the best possible fit with the 1932 tables, and then to classify the residuals afresh. This showed that further corrections reaching about 5^s for P and 9^s for S were still needed. Applying these, we obtained a new set of tables and proceeded till the process yielded no further changes. Actually it was found that the S residuals were much less consistent than those of P, and our solutions for the individual earthquakes rested on P alone.* Other phases were not treated till the solution for P was done.

At the same time attention was paid to other waves. Oldham † had noticed in 1906 that, while P reaches a distance of 100° in about 14^m, it takes about 20^m to reach 180°.‡ He found that the difference was too large to be attributed to distance alone ; it was necessary that there should be a drop of velocity at the greater depths. The consequences of this were worked out, partly by Oldham and very fully by Gutenberg.§ The times up to a little over 100° do not increase as fast as they should if the velocities were the same at all depths. It is necessary therefore that the velocities must increase with depth. This implies in turn, in accordance with the principle of least time, that the rays are convex upward, and solutions by various authors showed that the ray that emerges at 100° should have penetrated to a depth of about 0·4 of the radius. The velocity of P at short distances was about 8 km./sec., rising to about 13 km./sec. at this depth ; but to fit the time at 180° it must then drop to about 9 km./sec. The result would be that a ray striking this core would be sharply refracted downwards, and there would be a shadow zone. The nearer edge of the shadow was located by Gutenberg, by study of individual seismograms, at about 103°, which gave a radius of the core of about 0·55 of the outer radius. The further edge was found to be about 143°, where P reappeared with an enormous amplitude, falling off rapidly at greater distances. The phenomenon can be imitated optically by filling a spherical flask with water and placing a point source of light and a photographic plate on opposite sides of it at distances of about twice the radius. The ratio of the velocities of light in air and water is about the same as that of the velocities of P just outside and within the core. The rays of light are cut off by the plate before they reach a focus, but there is a caustic surface surrounded by a shadow. The plate shows, therefore, a very bright ring of light, corresponding to the large intensity about 143° ; outside this is shadow ; inside it there is illumination, but less intense.

The P wave that has passed through the core has been known at various times as P_4P_4P, P_cP_cP, P', $[P]$ and PKP. The latter, introduced by Sohon, is now in general use, though P' and $[P]$ are sometimes still used for compactness. K by itself is used for the phase inside the core. Gutenberg

* *Bur. Centr. Int. Assn. Séism., Strasbourg, Trav. Sci.*, Fasc. 11, 1935.

† *Q.J. Geol. Soc.*, **62**, 456–475.

‡ Distances are always given as angles subtended at the centre of the earth.

§ *Gött. Nachr.*, 125–176, 1914.

P. That given by *P* being called t_0, the average *S* residual, taking the same t_0, might be anything from about -12^s to $+8^s$. This was noticed first by Lehmann and Plett in their studies of the Peru and Marianne Is. earthquakes of 1928 July 18 and 1930 October 24.* The *S* and *SKS* residuals differed in these by about 15^s, which could not be explained by any permissible change of epicentre or t_0. Bullen and I had to decide which of these should be regarded as a typical earthquake, and chose 1928 July 18, on the ground that the early *S* and *SKS* on 1930 October 24 might be due to focal depth. This, as it turned out, was wrong.

For *SKKS*, *PKS*, P_2 and *SKSP*, other core phases, the observational material for any single earthquake was scanty, and we had to eliminate t_0 and *Z* as well as possible by means of *P*, *S* and *SKS*, and then combine the data for all earthquakes. *SKKS* seemed the most satisfactory, but the residuals even for it were very scattered.

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observing stations, because it was not clear to us then that even with geocentric distances the greater part of the effect would be taken into account, and because other outstanding errors seemed to need immediate attention, and their treatment could not be postponed until the ellipticity effect was worked out in detail. Since Bullen's return to New Zealand at the end of 1933, however, he has calculated it for all the relevant phases—a most laborious piece of work *—and allowance has been made for it. This was easy because the earthquakes used fell into a few well-defined geographical groups: South-Eastern Europe and Western Asia; North and Central America; Japan; South America; and Pacific Ocean. For earthquakes of one group the ellipticity correction would be nearly the same, and its values for a mean epicentre could be applied at the end of the work. The corrected times for the groups could then be combined, keeping the previous standard errors, since the correction was a known quantity.

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For S and SKS it appeared that further progress required a drastic selection of the earthquakes used. The residuals were much more scattered in some earthquakes than in others, and in some cases seemed to fall into two or more distinct series separated by several seconds. A mean including observations from two series would be representative of neither. At this stage, therefore, attention was confined to earthquakes with long series of S and SKS observations, consistent enough to indicate that nearly all stations over a long range of distance had read the same thing. The first work that indicated to me that there was something seriously wrong with the J.B. times was on the Afghanistan deep-focus earthquake of 1929 February 1. A long series of European stations about 40°–50° had read S, and many North American ones SKS. The former gave small residuals, the latter very consistent ones of about -12^s. The only possible explanation seemed to be that the J.B. times of SKS were about 12^s too long.* This was confirmed by three other well-observed shocks, the deep ones of 1928 March 29 and 1931 February 20, studied by Stechschulte† and Scrase,‡ and the Marianne Is. one of 1930 October 24, studied by Lehmann and Plett. Scrase had in fact remarked that $dt/d\Delta$ for S beyond about 70° in his study was less than my 1932 times gave, but the J.B. slope is larger than my 1932 one. I was not sure then that the difference was not due to some error in estimating the allowance for focal depth, but later work has fully confirmed it. Lehmann and Plett had given no observations of S and SKS within about 90°, but when the I.S.S. appeared I found that the observations at shorter distances suggested a value of Z of about -8^s instead of -20^s, as had previously appeared. The correlation between the distant S and SKS residuals in different earthquakes was very close and apparently attributable to variation of focal depth within the upper layers, and all the series indicated that both needed a reduction of about 12^s to correspond to S at moderate distances. It might have happened that a selection of special earthquakes, on the ground that the residuals varied unusually steadily against a standard table, would have led only to an underestimate of uncertainty; but if the steadiness was due to the same things having been read as S and SKS at most stations the apparent uncertainty would be valid. The χ^2 test sufficed to decide this. On the latter alternative χ^2 would agree with expectation on the hypothesis of randomness of the errors; on the former it would be too large, since if the more scattered residuals in other earthquakes were in fact random, and we had made an arbitrary selection, the means by ranges of distance would vary as much as ever while their apparent uncertainties would be reduced. The test gave a satisfactory value of χ^2, and showed that these are earthquakes with times of S and SKS that can be regarded as free from complications; we can now say that these are typical earthquakes and proceed to study the nature of the complications in the others.

The difficulties about S up to 20° have not been found soluble by means

* *M.N., Geophys. Suppl.*, **3**, 310–343, 1935.
† *Bull. Seism. Soc. Amer.*, **22**, 81–137, 1932.
‡ *Phil. Trans.*, A, **231**, 207–234, 1933.

of normal earthquakes alone. It occurred to me that it should be possible to test whether the readings at the stations referred to S by applying the criterion used by Lehmann to distinguish it from *SKS*. Special difficulties about S had been recorded by J. S. Hughes for the Italian earthquake of 1930 July 23, there being a special abundance of late readings. I collected the records of many of the stations for this earthquake, and identified S by the beginning of the change of direction of the movement. This came within a few seconds of the J.B. time, but several large movements followed, one or other of which had been read by most of the stations ; other stations had agreed with what I interpret as S from the change of direction.* No satisfactory explanation of the later and larger movements has been given. What is clear, however, is that they are not the theoretical S and their times are not relevant to the velocity of S ; and that their existence accounts for the huge scatter of the S residuals at short distances. In deep-focus earthquakes, however, the S residuals at short distances show a pronounced concentration with only the usual amount of background effect. A study of 10 such earthquakes in and near Japan, combined with the velocity at short distances found from European near earthquakes, has led to what appears a highly satisfactory determination of the times of S up to about 20°.†

Earthquakes in the northern hemisphere yield little information about *SKS* beyond 110°. It should theoretically exist to 180°, but to extend the information about it we have to use earthquakes in the southern hemisphere. This has been done, ‡ and we have now empirical times of *SKS* up to about 145°. Beyond this it is small and is confused by the arrival of *PPP* about the same time.

The irregularity of the S residuals in many earthquakes seems to be due to a peculiarity at the focus itself. Turner recorded several cases of what he called *high focus*, where the $S-P$ interval was longer than in what was considered a normal earthquake. He argued from these that normal earthquakes really occurred at a depth of about 250 km. But this was contradicted by the Montana earthquake, which showed the upper layer waves P_g and S_g, and therefore could not have a focal depth more than about 20 km., and which gave times of P and S agreeing well with those found by Turner himself for the average normal earthquake. The assumption of abnormally high focus is untenable. But the fact of these late S readings remains. It has been emphasized lately by Hughes, § and explained by Stoneley || and Tillotson.¶ Many earthquakes are not simple, two or more happening at the same focus at intervals of 6^s to 30^s, the second being often the larger. The result is that the observer, looking for the first movement, reads the P of the first ; but looking later for a large increase of movement superposed on the irregular movement following the P of the second, he reads the S

* *Gerlands Beitr.*, **49**, 393–401, 1937.
† *M.N., Geophys. Suppl.*, **4**, No. 7 (in the press), 1939.
‡ *M.N., Geophys. Suppl.*, **4**, 281–308, 1938.
§ *B.A. Report*, 1936.
|| *B.A. Report*, 1937.
¶ *Gerlands Beitr.*, **52**, 377–407, 1938.

of the second, and the apparent $S - P$ interval includes the interval between the shocks. This has been verified by tracing numerous "additional readings" following P or preceding S by about the same amount; comparing the first P with the first S, or the second P with the second S, the normal interval for the distance is found. It appears that this explains all the alleged cases of "high focus." It also accounts for a number of other discrepancies, in particular probably that about S on 1928 July 18. There seem to be cases where the first S in such earthquakes is read up to about 80°, but beyond that most stations read the second S and the second SKS. This is presumably the explanation of the large error made by Bullen and me at these distances.

The outstanding problems concern the structure of the upper layers, the 20° discontinuity, and the depth of the core. The special study of several European near earthquakes has given information about the former, and so has the work of Stoneley on surface waves. The near earthquakes, however, involve difficult readings. Combining them with Stoneley's results I have got 17 ± 3 km., 9 ± 3 km. for the thicknesses of the upper and intermediate layers, but I am not altogether satisfied that these accuracies are genuine—though many other discussions have given apparently higher accuracies to results that are certainly inconsistent with the data they are supposed to rest on. The deep-focus earthquakes give another type of evidence. If we adopt a standard structure for the upper layers we can find the focal depth from the observations of P at different distances. But given this depth we can also calculate the intervals $pP - P$ and $sS - S$; pP and sS being reflexions of P and S at short distances, first recorded by Scrase, and analogous to the rays that form the image in a concave mirror. They are reflected at the outer surface. Comparing the observed and calculated intervals we have information about the times of travel of P and S vertically through the upper layers, and therefore about the thicknesses of the latter. Using the surface wave equation but not the near earthquake one, I get 15 ± 3 km., 18 ± 4 km. for the thicknesses, and I am inclined to think that these are more satisfactory because pP and sS are not difficult to read. With these estimates it is now possible to make all times correspond to a surface focus, which is the most convenient standard of comparison. Previously we had introduced an additive constant into the time of P, so that it would be zero when extrapolated to the epicentre.

The radius of the core has until recently been estimated entirely from the position of the edge of the shadow zone for P. This method has two large uncertainties. The depth reached by a ray depends on $dt/d\Delta$ for P at the end of the range where it exists, and differentiation of an empirical table at its end is rather precarious. Also the shadow is not clear, a diffracted continuation of P extending to much larger distances. The former uncertainty corresponds, on present data, to a standard error of about 30 km. in the radius of the core; the latter is hard to estimate. Phases reflected at the core boundary seem likely to give much higher accuracy. $SKKS$ continues unsatisfactory, but PcP and ScS and the reflexions $PcPPKP$ and $ScSPKP$ are hopeful. The observations made by Scrase and

Stechschulte of *ScS* have led to the estimate 3472 ± 4 km. for the radius. The *PcP* readings are scattered and unsatisfactory, the place being apparently indistinct. These phases are not easily readable in normal earthquakes, but Gutenberg has succeeded in reading *PcP* on the short-period Benioff instruments. It is desirable that an important quantity like the radius of the core should be checked by as many types of evidence as possible.

Byerly's work and my earlier work showed that $d^2t/d\Delta^2$ for *P* is very large about 20°, and the same fact emerged in the early stages of the work with Bullen. About this time Lehmann made a special study of this region and found that beyond 20° there was a later *P*, which appeared to correspond to that at smaller distances, the first *P* being apparently a new phase.* These features would correspond to a discontinuous increase of velocity at a depth of about 480 km. There are, however, a number of difficulties of interpretation, notably the fact that the amplitudes about this distance are very large, which would agree with a rapid continuous increase of velocity but apparently not with a discontinuous one. The deep-focus earthquakes have here again given some useful supplementary information. They suggest that the *P* and *S* times in this region correspond, not to continuous curves, but to curves with loops, the refraction being so strong that parts of them run backwards. Continuous refraction strong enough to do this would fit all the data. The most likely explanation seems to be that of Bernal, that olivine adopts a different crystalline form at high pressures.†

Many attempts have been made to trace *S* waves through the central core, but the results are conflicting. Some observations seem to refer to *SKKS*, some to *SKSP*, some to *ScSPKP*, some to *PPS*. Others are doubtfully readings of genuine phases at all. It may be remarked that none of them has convinced Gutenberg, who produced the first trial table of what might be expected of *S* through the core. There are two types of evidence that indicate that the core is genuinely liquid. Adopting estimates of the rigidity from *S* in the shell, but treating the core as liquid, the tidal yielding of the earth as a whole can be calculated, and the results agree very well with the amplitude of the bodily tide and the period of the 14-monthly variation of latitude. With a rigidity in proportion to the bulk-modulus indicated by *K*, the calculated amplitude would be much too low and the latter period too short to agree with observations. It seems to be beyond reasonable doubt that for stresses with periods of 12 hours and more the core behaves as a liquid.‡ It might be theoretically possible that this could be true and yet that there could be a considerable rigidity for stresses with periods of a few seconds. This not very hopeful suggestion, however, is hard to reconcile with the size of *SKS*. In entering the core this undergoes refraction with change of type from *SV* to *P*, and this is reversed in emergence. Now in all such cases that have been worked out for transitions between solids the refracted wave of the changed type is small. Yet *SKS*, in spite of having undergone two such refractions and lost much energy to

* *Geod. Inst. Copenhagen, Medd.*, **5**, 1934.
† *M.N., Geophys. Suppl.*, **4**, 50–72, 1937.
‡ Jeffreys, *M.N., Geophys. Suppl.*, **1**, 371–383, 1926.

ScS, *SKKS* and *SKP*, is comparable in size with *S*. This seems to indicate that the core must be fluid even to the shortest periods.

A branch extends from *PKP* at 143° and runs back to about 120°. This has usually been considered to be diffracted from the caustic surface, but strong doubts have been expressed about this explanation by Lehmann and Gutenberg, mainly on the ground that short periods occur in the motion. I have not been wholly convinced by the latter argument, since diffraction near a caustic and around an obstacle may be two very different things. But the size of the movement shown in a record reproduced by Gutenberg and Richter * does seem convincing. To account for it we seem to need a much more complicated distribution of velocities in the core than has yet been considered.

An essential feature of the work since my 1936 Strasbourg paper has been the regular use of the χ^2 and other significance tests to test whether the apparent standard errors are genuine. Internal correlations and systematic errors are very liable to lead to underestimates of uncertainty, since the usual estimates of the standard error rest on the hypothesis that the errors of observation are independent. But this can be checked by comparison of different earthquakes or batches of earthquakes from different regions, since if we have made an underestimate it will be shown by too large a χ^2 for the comparison. In most cases no anomaly has been found ; when one has been found it has either been traced by further examination of the data, or, if there has been no apparent explanation, the estimated uncertainty has been increased to allow for it.

HAROLD JEFFREYS.

* *M.N., Geophys. Suppl.*, **4**, 363–373, 1938.

COMETS

The year 1938 was remarkable for the scarcity of comets, and the only one observed was Comet Gale (1927 VI). An ephemeris had been given in the *Handbook of the British Astronomical Association* and the time of perihelion was taken as 1938 April 19·6. Computations of orbits from previous observations were made by Miss Makemson, Dr. Crommelin and Dr. Innes, and they had found periods of 11·03, 11·11 and 11·19 years respectively. The mean of these was adopted when perturbations were applied in the computation of the new orbit. Early in April Mr. Gale wrote to say that he had searched for the comet on 20 mornings without success, and it was not until May 1 that it was discovered by Mr. L. E. Cunningham of Harvard. He had computed an independent orbit and had found the time of perihelion May 16·896—nearly a month later than the time adopted by the *B.A.A.* computers. He made five search ephemerides with different values of T from April 14·9 to June 17·9, and with the ephemeris from the last value of T he found the comet. The large discrepancy between the time of perihelion and that adopted in the *B.A.A. Handbook* accounted for the fact that the comet was $5^h\ 23^m$ west of the position predicted in the *Handbook*. The actual time of perihelion was just over half a day later than Cunningham's assumed date, June 17·9. At the time of discovery its magnitude was 10, and it was estimated that it would be 8 at perihelion; but when Mr. A. E. I. Forbes at the Cape observed it about the time of perihelion he described it as diffuse with magnitude 9. It is now known as Comet 1938 *a*.

The comet is interesting from the fact that it made a near approach to Jupiter in 1917, to which attention was drawn by Innes in *Memoirs of the British Astronomical Association*, Part 1, p. 14. The possibility of this close approach, indicated by an early orbit, was, Innes states, responsible for stimulating his interest in the comet.

M. DAVIDSON.

SOLAR ACTIVITY

Sunspots.—As stated in the 1938 report, the year 1937 was one of very high sunspot frequency. The year 1938 has likewise been notable for sunspots, but there are indications that the maximum—the highest since that of 1870—is now past. Anticipating a decline of solar activity during 1939, it may be said in advance of final data that the maximum of the current 11-year cycle appears spread over the two years 1937–38 with two pronounced peaks in 1937 July and 1938 July.

A comparison of the three years of sunspot activity 1936–38 is given by the following data to which the number of magnetic storms observed at Abinger has been added. Areas of sunspots are corrected for foreshortening and are expressed in millionths of the Sun's visible hemisphere.

Year	1936	1937	1938
Mean daily sunspot area (Greenwich)	1141	2073	1900*
Wolf Sunspot Number (Zürich)	79·7	114·4	105†
Number of large sunspots :			
1000–2000 units in max. area	7	13	10
2000–3100 „ „ „	0	3	4
Magnetic Storms ‡	9 (0)	26 (3)	28(5)

* Approximate value. † Mean of first six months.
‡ The number of "great"storms is indicated in brackets.

The time (U.T.) of central meridian passage and latitude of each of the fourteen groups of spots of area ⩾ 1000 millionths of the Sun's hemisphere recorded during 1938 are as follows :—

(1) Jan. 11·5	20° N	(8) July 10·7	13° S
(2) Jan. 18·4	18° N	(9) July 15·1	11° S
(3) Feb. 10·2	25° S	(10) Sept. 27·7	12° S
(4) Apr. 14·1	27° N	(11) Oct. 11·9	17° N
(5) May 10·4	8° S	(12) Nov. 10·8	9° S
(6) May 23·8	8° N	(13) Nov. 15·7	18° S
(7) July 7·2	14° N	(14) Nov. 28·8	14° N

Group (2) reached an area of 3100 millionths and was markedly active in *Hα*, 36 bright chromospheric eruptions being collectively observed during its transit. Groups (6) and (14) had each a very rapid growth from 10 units to 1000 units and from 150 to 1200 units respectively within 48 hours. Group (4) was active spectroscopically, 22 bright eruptions being recorded. Group (11) maintained a high average area during its transit of the disc with a maximum of 2900 millionths. Judging from the Greenwich observations, chromospheric activity associated with this spot was, however, subnormal (*Observatory*, **61**, 310, 1938). Nine out of these fourteen large groups of spots were associated with magnetic storms occurring within 4·0 days of the respective times of central meridian passage ; in two other cases there was magnetic disturbance just below storm-strength. Groups (6), (11) and (13) had no association with magnetic activity within the time-limit defined above.

During 1938, twenty-eight magnetic storms were recorded at Abinger, five being "great" storms. Those of special interest were (*a*) the great storm of January 25–26 associated with the brilliant aurora seen extensively from Europe during the evening of January 25. The ranges of the magnetic elements recorded at Abinger were 125′ in D, 1040 γ in H and 570 γ in V. No large sunspot was near the Sun's central meridian at the time of the storm, the great spot (2) having just passed round the west limb. (*b*) The great storm of April 16 with the exceptionally large range in D of 5° 7′, 1375 γ in H and 495 γ in V ; the bulk of the storm occurred within ten hours. The large and active sunspot (4) was near the central meridian at the time of the

storm. (*c*) The great storm of May 11–13 (ranges 80′ in D, 960 γ in H and 420 γ in V) associated with an aurora observed from Greenwich at about 0^h on May 12 in bright moonlight. A large sunspot (5) of average spectroscopic activity was one day past the central meridian at the time of commencement of the storm.

It may be noted that during 1937 and 1938, magnetic storms showed a distinct preference to occur when the longitude of the Sun's central meridian was between 70° and 190°. Large sunspots over the same period did not, however, show this definite preference in their longitude distribution.

H. W. NEWTON.

Prominences, 1938.—During 1938 there has been a slight decrease in almost all forms of prominence activity except the areas which show an increase over the previous year.

The mean daily areas and numbers of calcium prominences as derived from Kodaikanal photographs are as follows :—

Areas

	North	South	Total
1938 January to June	4·91	2·93	7·84 sq. mins.
July to December	4·21	4·33	8·54 „

Numbers

	North	South	Total
1938 January to June	8·35	6·65	15·00
July to December	7·61	7·00	14·61

Prominence areas show an increase of 12 per cent., whereas the numbers show a decrease of 6 per cent. when compared with the previous year. The northern hemisphere shows a slight preponderance of activity over the southern. The distribution of areas and numbers in latitude showed a tendency to increase in low latitudes up to 40° and to decrease in zones of higher latitudes. During the second half of the year the high latitude peak became unimportant, so that the activity was confined mainly to within 60° of the equator in both the hemispheres.

Forty-eight metallic prominences were observed during 1938 as against 60 in the previous year. Of these 20 were observed in the northern hemisphere and 28 in the southern hemisphere, and all these were between latitudes 4° and 36°. Displacements of the hydrogen line in the chromosphere and prominences observed during the year with the spectroscope numbered 323 as against 369 in 1937. Of these 176 were towards the red, 124 towards the violet and 23 both ways simultaneously. The largest displacements noticed were 6 A to red and 8 A to violet.

Bright reversals of the $H\alpha$ line over the Sun's disc observed with the spectroscope in the neighbourhood of sunspots numbered 872 as against 891 in the previous year. The displacements observed in the neighbourhood of sunspots numbered 65 as against 73 in the previous year. Of these

43 were towards the red, 8 towards the violet and 14 both ways simultaneously. D_3 was observed as a dark line on 789 occasions as against 826 in 1937.

The displacements observed in prominences with the spectrohelioscope numbered 187 as against 259 in the previous year. Of these 97 were in the northern hemisphere and 90 in the southern, and 100 were on the east limb and 87 on the west limb. Displacements to the red numbered 99 and those to the violet numbered 88. The largest displacement in prominences observed in 1938 was 4·0 A to violet.

Eruptive prominences on the limb were photographed on January 25, April 6, May 6, December 24 and December 30. The greatest height recorded was 13′ on May 6 S.E. limb. The prominence of December 24 rose in latitude N. 20° on the west limb and poured into a centre of attraction in latitude S. 64°. There was no sunspot area in the neighbourhood. A striking feature of the prominence was the spiralling of the entire mass.

The mean daily areas of prominences projected on the disc as hydrogen absorption markings amounted to 10161 millionths of the Sun's visible hemisphere as against 9490 millionths in the previous year, showing an increase of 7 per cent. Their distribution in latitude is similar to that of calcium prominences, except that the activity in the zones 20° to 25° in the northern hemisphere and 15° to 20° in the southern hemisphere is more pronounced in the case of $H\alpha$ absorption markings.

A. L. NARAYAN.

DOUBLE STARS

New Pairs.—Mem.R.A.S., vol. **66**, part 1, contains Rossiter's third list of new southern double stars, discovered with the 27-inch refractor of the Lamont-Hussey Observatory, Bloemfontein. The greater part of these pairs are between the equator and −20°, so that they will also be of interest to observers in the northern hemisphere. The numbers in this list are Rst 3340–4139.

Olivier gives 14 new pairs in *A.J.*, **47**, 100, and Kuiper 11 new close bright binaries in *P.A.S.P.*, **49**, 340. Luyten has a note on a possible companion to Fomalhaut and some other pairs of stars (possible common proper motions) in *A.J.*, **47**, 115.

Measures.—Aitken (*L.O.B.*, **18**, 109) gives measures of 1865 pairs of his own discovery, and (*L.O.B.*, **18**, 53) measures of 108 pairs for which Miss Moore has computed the dynamical parallaxes.

Baize (*J.d.O.*, **21**, 141 and 161) publishes his measures with the Paris 12-inch refractor (a few with the 15-inch), Miss Bonnet gives her measures with the same instrument (Paris Observatory separate publication) and Giacobini (*J.d.O.*, **21**, 33) his later measures with the 15-inch.

Dawson (*La Plata*, vi, 6) gives his third series of measures with the 17-inch; Duruy has continued his observations with an 11-inch refractor (*J.d.O.*, **21**, 97). Greenwich Astronomical Results for 1935 contains

micrometer measures with the 28-inch; *Mem. Soc. Ast. Ital.*, xi, 1, has measures by Lacchini with a 10-inch; *J.d.O.*, **21**, 113, by Muller with the Strasbourg 6-inch; and *M.N.*, **98**, 223, Milburn's 29th series with the 24-inch reflector. *M.N.*, **98**, 88, has another series by Phillips with the 8-inch; *A.N.*, **226**, 129, by Schembor with the 8-inch; and *U.O.C.* 100 the 23rd series of micrometer measures by van den Bos.

Photographic measures of o_2 Eridani are given by van de Kamp (*A.J.*, **46**, 195), of ADS 2427 by Reuyl (*P.A.S.P.*, **49**, 335), while Urban gives a series in *A.N.*, **266**, 197.

Orbits:—

ADS	Computer	*P*	*a*	*e*	Reference
			"		
450	Finsen	10·5	0·143	0·55	*U.O.C.* 99.
755	van den Bos	169·3	1·013	0·324	,, 100.
2200	van den Bos I	31·6	0·220	0·76	,, 99.
	,, II	63·1	0·200	0·00	
2799	Danjon	63·48	0·472	0·58	*J.d.O.*, **21**, 47.
2959	Varchon	594·65	2·71	0·746	*J.d.O.*, **21**, 12.
7284	van den Bos	34·20	0·660	0·35	*U.O.C.* 99.
8035	Jones, Furner	44·0	0·634	0·35	*M.N.*, **98**, 92.
8148	van den Bos	414	3·60	0·55	*U.O.C.* 99.
8337	Finsen	77·1	0·383	0·47	,, ,,
8539	Woolley	∞	∞	1·00	*M.N.*, **98**, 380.
8987	van den Bos	22·60	0·220	0·54	*U.O.C.* 99.
9094	Finsen	38·4	0·200	0·41	,, ,,
9229	van den Bos	321	0·898	0·88	,, ,,
9247	,,	40·0	0·240	0·25	,, ,,
14073	Finsen	26·60	0·480	0·35	,, ,,
14424	,,	133	0·410	0·27	,, ,,
16326	van den Bos	90·0	1·000	0·82	,, 100.
16665	Tannenbaum	108·0	0·831	0·80	,, 99.

Alden, from measures on parallax plates, gives the apparent orbit of α Phoenicis (*A.J.*, **46**, 189) and Cin 1988 (*A.J.*, **47**, 9).

No less than three catalogues of orbits have been published this year: by Ekenberg (*Medd. Lund.*, ser. II, No. 94), by Baize (*Bull. Ast.*, x, 273) and by Finsen (*U.O.C.* 100). The first is a supplement to Luplau Janssen's earlier catalogue of that type, and lists all orbits known to the editor; the other two give the most recent or most satisfactory orbit. Finsen has, wherever required, changed the elements as published to conform to the system advocated by the I.A.U. (*Transactions*, vol. v, 332) and has classified the orbits according to reliability.

It may be suggested that, in future, astronomers planning to publish such a catalogue should get into touch with the president of I.A.U. Comm. 26, so that unnecessary duplication of work may be avoided and the requirements of such a publication be agreed upon.

Miscellaneous.—Baize (*L'Astronomie*) writes on some interesting binaries and has a note on Sirius; in *A.N.*, **264**, 245, he mentions the rapid orbital motion of Furuhjelm 46, one of Kuiper's discoveries. Danjon (*J.d.O.*, **21**, 29) writes on the possible triplicity of ADS 9578; Burns (*P.A.S.P.*,

50, 49) mentions an interesting optical pair, and Holmberg (*Medd. Lund.*, II, 92) conjectures invisible companions as revealed by means of modern parallax observations. Rabe (*A.N.*, **265**, 177) gives a paper on orbit determination and correction based on short observed arcs; Danjon (*C.R.*, **206**, 322) on orbital elements of visual binaries; Berglund (*Medd. Lund.*, II, 99) on the orientation of the orbit planes of visual binaries; and Gabovits (*Tartu Publ.*, **30**, 1) on the empirical mass-luminosity relation and on the orientation of orbit planes in multiple systems.

Liebermann (*A.N.*, **264**, 221) writes on colours and magnitudes of double stars, Alden (*A.J.*, **46**, 177) gives a method for determining the difference in brightness of the components of double stars. Photographic determinations of mass ratio are given by van de Kamp (for Kr 60; *A.J.*, **47**, 1), by Wirtanen (for μ Ori; *A.J.* **47**, 4) and by Barcus (for ξ UMa; *A.J.*, **46**, 193).

Davidson and Symms (*M.N.*, **98**, 176) describe the comparison image micrometer, of a modified Hargreaves type, made for the 28-inch Greenwich refractor, and give some results obtained with this instrument.

Hertzsprung (*P.A.S.P.*, **49**, 309) writes on collaboration in astronomy; the second half of this paper deals chiefly with photographic observation of double stars.

W. H. VAN DEN BOS.

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ADDRESS

Delivered by the President, Dr. H. Spencer Jones, on Some Problems of Meridian Astronomy

The present occasion being one when the President has freedom of choice of the subject for his Address, I have decided to select a subject that has not for many years been dealt with in a Presidential Address. It is not inappropriate, perhaps, that meridian astronomy should provide the subject for this address. The warrant for the appointment of John Flamsteed as first Astronomer Royal, dated the 4th day of March, 1674–5, directed him "forthwith to apply himself with the most exact care and diligence to the rectifying the tables of the motions of the heavens, and the places of the fixed stars." From the foundation of the Royal Observatory, Greenwich, such observations have continued to form a principal part of its work.

The times when the positions and motions of the heavenly bodies were the prime concern of the astronomer have passed long since. Astronomy has branched out into one new development after another ; the bounds of space have been pushed further and further outwards. These newer aspects of the subject have proved of enthralling interest, in comparison with which meridian astronomy seems merely prosaic. Yet it is not without its problems ; these problems are not devoid of interest and their solution is not unattended with difficulties.

The purpose of meridian astronomy is to provide a fundamental system of reference, as free as possible from systematic errors of any sort. This system of reference is defined by the positions and proper motions of a network of stars distributed with reasonable uniformity over the whole sky, together with the numerical value of the constant of precession.

Our observations are made from a moving and rotating Earth. It is convenient to use the equator as a plane of reference and the equinox as a zero point. The determination of the positions of the equator and equinox is not without its difficulties. Both the equator and equinox depend upon the motion of the Earth and the motion of its axis ; they can therefore be determined by observations of the Sun which, in effect, fix the orbit of the Earth. But observations of the Sun are peculiarly liable to personal errors of a systematic nature, which are dependent also upon the method used for registering the observations. The eye and ear method of observation gave place to the hand-tapping method, in which the instants at which an object crosses the fixed vertical wires in the focal plane of the transit instrument are electrically recorded on a chronograph by pressing a hand-tapper to close the circuit ; the hand-tapping method has in turn been almost entirely superseded by the use of the impersonal micrometer, in which a moving wire is traversed across the field at such a rate that it moves with the object that is being observed, contacts being automatically closed when the moving

wire reaches certain positions in the field. Both these changes in the method of observation changed the mean personal equation in the observations of the Sun. The uncertainty in the amount of these changes is such that it is still not possible to say whether or not a correction is needed to the motion of the equinox as defined by Newcomb.

The differences in personality in the observations of stars by the hand-tapping method could amount to a few tenths of a second of time. The change to the impersonal micrometer has reduced these to a few hundredths of a second. The observation of the Sun or of a planet showing a perceptible disk is essentially different from the observation of a star ; relative personal equations in star observations are not applicable to Sun or major planet observations. The personal equations in the observation of the Sun are liable to be larger and to show greater variations than the personal equations in observations of stars.

The bright inner planets can be used for fixing the equator and equinox, because each observation of a planet involves the elements both of the orbit of the planet and of the orbit of the Earth. By the accumulation of sufficient observations the effects depending upon uncertainties in the orbital elements of the planet can be disentangled from those relating to the Earth's orbit. But the personal errors in the observation of an inner planet, showing a perceptible disk and variations of phase, are not the same as those affecting star observations and are complicated by dependence upon the phase of the planet. There is the further difference that the planetary observations are necessarily made by day, whilst the star observations are mostly made at night.

It was therefore suggested by Sir Frank Dyson that the minor planet Vesta should be used to determine corrections to the equator point and equinox. Vesta is sufficiently bright for observation with the impersonal micrometer, it has a star-like image and is observed at night. The observation of Vesta is therefore essentially similar to a star observation and is affected by the same personality errors. A general theory of its motion by Leveau is available, but this is not sufficiently complete and accurate. Many observations of Vesta have been obtained, however, in recent years and compared with ephemerides based on Leveau's tables. If a satisfactory theory of the motion of Vesta were available, these observations could be utilised.

In the meantime plans have been developed for utilising a larger number of minor planets to control not merely the equinox and equator point, but also errors of a systematic nature, varying with right ascension and declination, in the fundamental system of reference. The system of reference provided by a fundamental system is necessarily based upon observations at many different observatories and with many different instruments. Each meridian instrument has its own peculiarities : although there have been great improvements in the design and construction of instruments, refinements in the methods of observation—carrying with them the elimination of the greater portions of the personal and magnitude equations in star observations—more careful determination and control of instrumental

errors, and considerable increase in the precision of clocks, there still remain serious systematic differences between the best modern catalogues, particularly in declination.

In illustration of instrumental peculiarities the reversible transit circle of the Cape Observatory may be mentioned. This instrument was designed by Sir David Gill with much thought and care. It can be reversed in its bearings, giving two positions for observation, denoted by E and W; object-glass and eye-end can also be interchanged, giving the two arrangements denoted by I and II. Four separate combinations are therefore possible. After allowing for the difference in horizontal flexure in the two conditions I and II, the difference in declinations measured in the two conditions has a regular run amounting to $0''{\cdot}4$ from Dec. $+40°$ to the S. Pole. The difference between the two positions E and W in both conditions has a range of $0''{\cdot}18$, but the difference is systematically larger in condition II than in condition I, the extreme differences being $0''{\cdot}3$ and $0''{\cdot}2$ respectively.

A new reversible transit circle, whose design was based largely on that of the Cape instrument, has recently been provided at Greenwich and has been undergoing detailed investigation before being employed on a programme of fundamental observations. Some of the results of this investigation appear to throw light on the various ways in which instrumental peculiarities may affect the observed star-places.

When transits of stars were observed in the normal way with the motor-driven micrometer wire it appeared that, relatively to the positions in the FK3 Catalogue, the stars near the pole, when observed either above or below pole, appeared to transit too early as compared with equatorial stars, the magnitude of the error being about half a second of time at 7° from the pole. Discordances of the same amount were observed when the moving wire was driven by hand. But when observations were made by tapping transits across the fixed wires, no appreciable deviations from the FK3 places were found. This proved conclusively that the trouble was in the micrometer; the observations could be accounted for if the moving wire lagged behind the micrometer screw by about 12 microns, corresponding to one second of arc.

The equipment included two tape chronographs, each with three pens for hand-tapping, time and micrometer records. The purpose of the three pens was to enable close circumpolar stars to be observed by driving the moving wire at equatorial speed and, by using the reversing gear, transiting it backwards and forwards in the field of view across the star, the instant of each transit being recorded on one pen of the chronograph by means of a tapping key; the other two pens record the clock time and the reading of the micrometer head. If the supposed lag of the moving wire existed, the observation of a close circumpolar star should give a different result when observations were made by this method from that given by the normal method with the wire moving with the star. A selection of circumpolar stars was observed by both methods and a difference in right ascension of $0^{s}{\cdot}44$ at $5\frac{1}{2}°$ from the pole was obtained, corresponding to a lag of the wire behind the screw reading of amount $0''{\cdot}7$. Observations on the collimators

showed no backlash in the ordinary sense, and it thus became apparent that the lag developed only when the micrometer was in continuous motion. The micrometer was returned to the makers for correction. The frame carrying the moving wire is constrained to move along a guiding rod by two sets of bearing surfaces, and motion in a direction perpendicular to the plane of the frame is prevented by a tailpiece, which bears in a slotted slide. Examination revealed that the guide rod was slightly convex to the eyepiece and that the guiding slide of the tailpiece formed a constraint and required easing. These defects were rectified by the removal of very small amounts of metal, and when the micrometer was brought into use again the lag was found to be negligible.

It was fortunate, perhaps, that the magnitude of the discordance was so great, as it might otherwise have remained undetected. The lag is now checked at regular intervals by a purely instrumental method not involving star observations. The moving wire is driven backwards and forwards at equatorial speed, and the instants of transit across a fixed wire in the field are tapped off; the wire is then driven at a slow rate corresponding to that of a close circumpolar star, and successive transits, backwards and forwards, are again tapped off. It is satisfactory to find that the lag has remained negligible in amount.

A further defect was found by setting the moving wire on one of the fixed wires and reading the position of coincidence. The micrometer readings for the position of coincidence varied with the position of the instrument, the range of the readings amounting to about half a second of arc. This meant that the reading corresponding to the line of collimation would vary with the declination. The magnitude of the effect was not the same with all the fixed wires, and the observations suggested a looseness of the R.A. wire system at one end of the field. The defect was cured at Greenwich by a simultaneous adjustment of the screws clamping the guide rod to the main casting of the instrument and those holding the bearing surfaces of the wire frame against the guide rod. The adjustment is tested at intervals of a few months and has so far remained permanent.

Similar tests were made on the Z.D. micrometer by setting on a speck of dust on a fixed wire, and a variation of the position of bisection with the position of the instrument was found. It has not been found possible to reduce the range of the effect below about $0''{\cdot}2$, the extreme values being found in the north and south horizontal positions of the telescope. The effect can be allowed for, but an undetected discordance of this nature would obviously enter directly into the determination of horizontal flexure and give a spurious result.

The observation of transits of stars for which the special circumpolar method is not used are made by obtaining five entirely independent bisections of the star image by the moving wire, the micrometer wire being deliberately thrown off the star after each bisection and a new bisection made. The precision of the observations is so great that on some nights a definite run in the clock error could be detected, amounting in extreme cases to a few hundredths of a second of time over a period of four hours

or so. This was provisionally attributed to drifts in the collimation and level, and a series of observations was undertaken and is still in progress in which the collimation and level are observed at frequent intervals during the day and evening. The collimation is found to be slightly variable and to be correlated with the difference of temperature between the dome and the tube of the telescope. The variations of level are related to small variable differences of temperature between the two piers, and the run in level is dependent upon the direction of the wind—whether the wind is blowing mainly on the east or west pier. With smoothed values of collimation and level, cases of drift in clock error are very rare. The frequent observation of collimation and level consumes much of the observational time, however, and it is hoped that the dependence of the variations of these errors on temperature effects will eventually be so closely tied down that less frequent observation of the errors, combined with records of temperature variations, will enable curves showing the variations of the errors to be drawn.

It is already clear that the considerable time spent in elucidating the peculiarities of the instrument has been fully justified and that the value of the observations made with the instrument will thereby be much enhanced.

The adjustment of the differences between different star catalogues, for the formation of a fundamental system, must be done to a large degree empirically. Boss combined northern and southern observatories and adjusted the coefficients of refraction used in the reduction of the observations at the two observatories so as to secure approximate agreement where the northern and southern observations overlapped. But, as Kopff has pointed out, when this procedure is used for modern catalogues corrections are obtained to the constant of refraction that are quite inadmissible. This procedure, which seems *prima facie* to have some justification, is therefore really empirical. It is the instrumental peculiarities that are of prime importance, and the most hopeful way in which increased accuracy in the establishment of the fundamental system can be obtained in the future seems to be by the more thorough investigation and study of the peculiarities of each instrument.

Instrumental flexure is a great difficulty in declination observations. It is usual to determine the horizontal flexure by observations with the collimators. But in such observations small displacements of wire frames or wires are interpreted as flexure, though such displacements may not follow the same law as true flexure with variation of zenith distance. The Cape reversible transit instrument gives different values for the horizontal flexure in the E and W positions for both conditions of the instrument, and there is, moreover, a marked seasonal variation in the observed horizontal flexure. The observations are reduced with a mean value of the flexure, and this may introduce a term of a seasonal nature in the observed declinations.

Observations of circumpolars fix the position of the pole ; the nadir is determined with a mercury horizon and the equator point is fixed by the

Sun and planets. In general the three points so fixed are not in agreement with the adopted refraction and the observed horizontal flexure. We can discard the observed flexure and replace it by an empirical term; we can correct the adopted constant of refraction; we may also have reason for supposing that the refraction in a northerly direction is different from that in a southerly direction. It is obvious that the adjustment involves the exercise of some judgment.

Coming to the right ascensions, the catalogues suitable for incorporation into a fundamental system are those in which the clock star-places have been corrected by the observations themselves. There are three methods by which this may be done. The Greenwich method is to observe the clock stars in groups of many hours (12^h and 6^h groups); the method used at the Cape, where the watches are restricted to about four hours, is to compare the clock error derived from day observations with the clock error interpolated from observations the preceding and following night and to analyse the differences, including a constant to represent a difference in personality between day and night observations or the effect of a diurnal term in the clock rate; the method used at Pulkowa is to divide the clock stars into groups which are connected with each other in much the same way as different groups are connected in observations for the determination of the variation of latitude. The considerable improvement in the precision of clocks within the past twenty or thirty years has greatly facilitated the control of the right-ascension system.

The proper motion system must be largely based upon series of catalogues observed over many years with the same instrument, as the effects of instrumental peculiarities are then largely eliminated. The Greenwich, Pulkowa and Cape series are of predominant importance for this purpose, and the proper motion system of the FK3 system depends primarily upon these three series of observations.

To combine the different catalogues into a fundamental system, corrections to each catalogue of the form $\Delta\alpha_\alpha$, $\Delta\alpha_\delta$; $\Delta\delta_\alpha$, $\Delta\delta_\delta$ must be determined. The adjustment of many different catalogues to the best composite system is a long and intricate task, involving much skill and judgment as well as a detailed knowledge of the methods of observation used to derive each catalogue.

The two principal fundamental systems based on the observations up to about the end of the nineteenth century were those of Auwers (Neue Fundamentalkatalog des Berliner Astronomischen Jahrbuchs or N.F.K.) and of Lewis Boss (Preliminary General Catalogue or P.G.C.). Both of these systems have been extensively revised, and the recent publication of the new catalogues, the Dritter Fundamentalkatalog des Berliner Astronomischen Jahrbuchs or FK3 (*Veröff. des Ast. Rech. Inst.*, No. 54, 1937) and the Albany General Catalogue (*Carnegie Inst. Special Pub.*, No. 468, 1937) are events of major importance.

A fundamental system of reference must necessarily be based in the main upon bright stars, because for control of errors of a periodic or seasonal nature observations must be made by day as well as by night; the

determination of azimuth error of a meridian instrument free from errors of star-places must be based either on the observation above and below pole of close circumpolars or on the observation at night of the below-pole transits of stars which transited near the zenith in the daytime. It is also mainly the bright stars for which the proper motions are known most accurately.

The original selection of stars by Auwers for his fundamental system comprised 905 stars, distributed fairly regularly over the sky, whose proper motions could be obtained with accuracy, together with 10 close northern circumpolars and 10 close southern circumpolars. A total of 925 stars is sufficient to define a system; but for many purposes, as, for instance, for the determination of time, the number is insufficient. 662 additional stars were therefore selected by Kopff, for which good positions and proper motions could be derived. 52 double stars, with separations between $0''{\cdot}5$ and $5''$ have been omitted from the original list of Auwers, so that the present FK3 fundamental system comprises a total of 1535 stars, uniformly distributed over the whole sky. A volume containing the apparent places of these 1535 stars will be published annually by the Nautical Almanac Office, commencing with the volume for the year 1941, the material being contributed by the American, French, German and Spanish ephemeris offices.

The revision of the N.F.K. system to give the new FK3 system has revealed one fact of great interest. The amplitudes of the differences, both in right ascension and declination, between the N.F.K. and modern catalogues are considerable. Going backwards in time the amplitudes become smaller and are a minimum about 1860 to 1870. Going still further back the amplitudes increase again, but the differences change sign. It is apparent, therefore, that the Auwers system, at the epoch of its formation, provided a fairly correct system of reference, but that there were considerable systematic errors in the proper motions in both co-ordinates. These were introduced by the incorporation of the observations made with the older instruments, and particularly by the observations in Bradley's great catalogue of 1755. The proper motions of the revised FK3 system have been based entirely on the modern observations extending from about 1850 to 1925. It is undoubted that this system is the best available at the present time. That some further revision of the proper motions will be required in the future is undoubted, but it will probably not be until the proper motions can be based entirely on observations made with impersonal micrometers that we shall obtain a system that can be regarded as practically final. Professor Kopff and his collaborators are to be congratulated upon the care and thoroughness with which the revision of the Auwers system has been carried through.

The Auwers system contained only stars with sufficiently reliable positions and proper motions to form a fundamental system of high precision. It was intended to form the framework for the great project of the A.G. Zone Catalogues, which were to include all stars down to the ninth magnitude in the northern heavens, and later in the southern heavens also. The

observations were to be repeated fifty years later for the derivation of the proper motions. The repetition, by photographic methods, is now in progress.

The Boss system was derived with a different object. The primary aim of Lewis Boss was to derive satisfactory proper motions of as large a number of stars as possible. This necessitated extensive discussion of the systematic differences between various catalogues and the formation of a fundamental system. The Boss system was defined by his catalogue of 627 standard stars. A list of some 4000 stars was selected for the formation of a Preliminary General Catalogue; this number was increased by 1112 stars, which were specially re-observed at Albany to strengthen their proper motions, and by a further 1100 stars, which were specially observed at the Cape. The Preliminary General Catalogue of 6188 stars, published in 1910, at once became, on publication, a standard reference catalogue for positions and proper motions. The General Catalogue, which was to complete the project, was to contain about 20,000 stars, including all stars brighter than magnitude 7·0, together with some thousands of fainter stars for which reasonably accurate proper motions could be determined. This programme was considerably extended and 33,342 stars were finally selected for the General Catalogue.

The southern stars were observed at San Luis in the Argentine, where the meridian circle from Albany was erected, between 1909 April and 1911 January. In these twenty-two months, 87,000 observations were obtained, undoubtedly the most intensive meridian programme ever carried through. The northern stars were observed at Albany between 1907 and 1918, the observations being interrupted by the southern observations at San Luis; 110,000 observations were made at Albany.

The Boss system was revised, and positions and proper motions of all the stars were determined on the revised system. The great General Catalogue of 33,342 stars, in five volumes, prepared under the direction of Dr. Benjamin Boss, was published by the Carnegie Institution of Washington in 1937. This catalogue thus furnishes the positions and proper motions of as many stars as possible in a definite fundamental system and will be invaluable as a reference system for photographic observations. In publishing star catalogues based on photographic observations it is important that the catalogues should be related to a definite system. On plates covering an area of 25 square degrees or more there will be found a sufficient number of stars contained in the General Catalogue to serve as reference stars for the reduction of the plates.

In the revision of the Boss system it was decided to make no periodic correction to the right ascension system, and no use was made of observations of the Sun or planets in the revision of the system of declinations. The original Boss system gave less weight to the early catalogues than was given by Auwers; the revised Boss system gives them greater weight than they receive in the FK3 system, because a number of catalogues of date earlier than 1850 are retained for the derivation of proper motions. The FK3 system is the nearest approach to a true system at the present time, but

the system of the General Catalogue can be directly related to it. The two systems are in close general agreement about epoch 1900, but diverge increasingly from each other before and after that date.

The use of Vesta for the control of equinox and equator point has led to more comprehensive schemes for utilising minor planets to control the fundamental system. Dneprovsky proposed that meridian observations of the first four minor planets should be obtained ; ephemerides for these planets were to be prepared by numerical integration. Numerov enlarged the scheme and suggested the use of 10 minor planets, for which both visual and photographic observations were to be obtained over a period of ten years. It was hoped that some sixteen observatories would co-operate, each of which would endeavour to obtain from 5 to 8 photographic observations of each minor planet in the six months around its opposition. The 10 planets selected by Numerov had small orbital eccentricities and inclinations. The choice of small eccentricities was to simplify the accurate calculation of the disturbed orbits by numerical integration ; the choice of small inclinations was to limit the observations to a narrow equatorial zone, thereby avoiding effects arising from variation of the errors of the fundamental system with declination, and enabling corrections to the orbital elements of the Earth and minor planet to be derived with greater accuracy. Plans for a meridian circle with aperture large enough to enable asteroids down to a magnitude of 11·0 to be observed were under consideration.

This scheme would control the equinox and equator point and the periodic errors of the right ascension system. Observations of each asteroid would provide corrections to the elements of the Earth's orbit, and from the whole series it was thought that the elements of the Earth's orbit might be derived with such accuracy that observations of the Sun need no longer be necessary. This project has not been further developed, I believe, probably because of the lamented death of Numerov. It suggested, however, to Brouwer a more ambitious project ; he took the view that if a programme of systematic observations of selected minor planets is to be undertaken, it should aim at gaining the maximum amount of valuable information. He considers that the aim should be a determination of the systematic corrections to the systems of both the right ascensions and the declinations, as functions of both right ascension and declination. The restriction in choice of suitable minor planets to those with small inclination was therefore deliberately given up. Fourteen minor planets were selected whose geocentric positions at oppositions during the interval between 1936 and 1946 were distributed with approximate uniformity over the whole area of the sky between declinations $+30°$ and $-30°$: subject to this requirement, preference was given to the longest known planets, to the bright planets, to planets with larger mean motions and to those with small eccentricities. The plan requires co-operation between a northern and a southern observatory ; each observatory should secure an average of 20 plates with two exposures on a plate within five months around each opposition of each planet, a total number of 2000 photographs at each station. The analysis of the observations will give corrections to the

elements of the Earth's orbit and of the orbits of the 14 planets and corrections to the fundamental system. These are assumed to be of the form

$$a_0 + a_1 \cos \alpha + a_2 \cos 2\alpha + b_1 \sin \alpha + b_2 \sin 2\alpha$$

in both co-ordinates. The material will be treated in six zones, ten degrees wide, so as to provide information about variations of the coefficients with declination. The corrections to the fundamental system therefore introduce 60 constants, and there are in all 164 unknowns to be determined.

Observations are being actively pursued. Meanwhile, Eckert and Brouwer have been investigating the methods to be employed in deriving corrections to ephemerides that have been calculated by mechanical integration. The scheme is a large and ambitious one, requiring the accumulation of much observational material and extensive computations for its analysis. Provided observations are obtained sufficiently far from opposition to enable the correction to the planet's longitude to be satisfactorily separated from the correction to the Earth's longitude, and provided the observations are well distributed in time, the corrections to the orbital elements should be satisfactorily separated from the corrections to the adopted system of star-places. If these requirements are satisfied, the programme should ultimately provide a good control over the fundamental system.

The determination of the constant of precession is ultimately related to the fundamental reference system and the assumptions that are made about it. Observations provide the positions of the stars relative to a rotating system of axes defined by a moving equator and a moving equinox. By comparing the positions at two different epochs we determine the annual variations in right ascension and declination. It is customary to separate these variations into two parts ; one part is due to the motion of the equator and equinox and involves the constant of precession, the remaining part is called the proper motion of the star. The determination of the constant of precession involves some assumptions, however, and if we change the constant of precession, the proper motions in turn are changed. As it is not possible to deduce the constant of precession with sufficient accuracy from planetary theory alone, we must bring in the stars to obtain a more accurate value. Determinations of the precessional constant have usually involved the assumption that the motions of the stars are distributed at random so that there is not, for instance, any general rotation of the stars relatively to the inertial reference system of planetary astronomy. The existence of two star-streams, as postulated by Kapteyn, a preferential direction of motion, as postulated by Schwarzschild, or the rotation of the galaxy, according to the theories of Lindblad and Oort, is not in accordance with the fundamental assumptions on which the Struve-Peters and Newcomb's values for the constant of precession were derived. The value obtained for the precession will depend upon the particular assumptions that are made. The interesting suggestion has been made, as a means of avoiding this inherent difficulty, that the distant galaxies should be used as a system of reference. The peculiar motions of these systems appear to be of the order of a few hundred kilometres a second, but their distances are

so great that we can assume that their angular motions are practically zero. If then the positions of a large number of the distant galaxies were determined with reference to neighbouring stars, whose positions were in turn related directly to the fundamental star system, we should have a means not only of correcting and controlling that system, but also of determining the constant of precession more exactly. A proper separation between the portion of the apparent movements of the stars that is due to precession and the portion that is due to the real proper motions of the stars would then be possible. No attempt has yet been made to connect the positions of the external galaxies with the fundamental system. That is a task for the future which promises to be of great value for meridian astronomy.

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